Development of Transmission Bus Load Model (TBLM)

Version 9

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1. Description of Function

All prior work (intellectual property of the company or individual) or proprietary (non-publicly available) work should be so noted. The form fields below and the cells of tables are where the author should enter text.

1.1 Function Name

Development of the Transmission Bus Load Model (TBLM)

Another equivalent name: “Development of Distribution Operation Model Aggregated at Transmission Buses”

1.2 Function ID

Identification number of the function

Replace this text with the function ID.

1.3 Brief Description

Describe briefly the scope, objectives, and rationale of the Function.

The Smart transmission operations will be very much impacted by the operations of the Active Distribution System, which will become a critical player in the overall power system operations. However, it is unrealistic to expect that the monitoring and control of transmission operations will reach out to every device in the distribution and customer domains. The end buses of the near-real time model of transmission operations will be the demarcation between transmission and distribution operations dynamics. Therefore, it is necessary to include the reactions and dynamics of the future distribution system into the operations in transmission, as well as integrating the new dynamic capabilities of the future distribution system to cooperate with transmission operations. These relevant dynamic properties of the distribution system should be **aggregated into the Transmission Bus Load Model** (TBLM) The TBLM should represent the aggregated load and available dispatchable load from the corresponding distribution system including all normal and emergency dependences of these loads on various impacting factors, such as voltage, frequency, demand response controls, price, etc. It should also represent the overlaps of different load management functions, which uses the same load under different conditions. For instance, if the same load is included in the Under-Frequency Load Shedding scheme and in the Under-Voltage Load Shedding schemes, the Energy Management System (EMS) contingency analyses should know what portion of the load will be shed. If the voltage drops first, the system could interpret what portion is left for the low frequency conditions, and so on. With such a dynamic model, updated by an Advanced DA application (mostly by DOMA) in near-real-time, the advanced EMS applications will be able to use adequate load models and additional aggregated controllable variables of the normal and emergency operations.

1.4 Narrative

A complete narrative of the Function from a Domain Expert's point of view, describing what occurs when, why, how, and under what conditions. This will act as the basis for identifying the Steps in Section 2. All actors should be introduced in this narrative. All sequences to be described in section 2 should be introduced in prose here. Embedded graphics is supported in the narrative.

High penetration of new technologies in the customer and distribution domains presents significant operational challenges and additional opportunities for transmission operations. DER-ES-Microgrids, Demand Response, Electric transportation, real-time-pricing, weather, and voltage/frequency sensitivities make the distribution grid a much more dynamic and active component of the entire power system. The comprehensiveness of the information exchange between distribution and transmission domains must be measured by the adequacy to the challenges of the Smart Grid.

The following EMS applications need to integrate a number of variables of the Smart Distribution Grid (Active Distribution Network):

1. For Normal Operating Conditions
    a. EMS monitoring functions (Wide Area Situational Awareness)

        - Topology monitoring (incl. states of controlling devices)
        - Transmission Bus load modeling (TBLM)
        - State estimation (SE)
        - Dynamic limit monitoring (DLM)
        - Network Sensitivity Analysis (NSA)
        - Reserve monitoring (RM)
        - Steady-state contingency analysis (SCA)
        - Dynamic security analysis (DSA)
        - Cyber Security Contingency Analysis (CSCA)
        - Intelligent alarm processing (IAP)

    b. Near-real-time EMS optimization and control functions
        - Optimal Power Flow (OPF), includes Volt/var
        - management
        - Security Constrained Dispatch (SCD)
        - Economic Dispatch (ED)
        - AGC
        - Ancillary functions

2. For Emergency Operating Conditions
    a. Near real time pre-arming and re-coordination functions
        - Load-shedding (LSh)
        - Generator-shedding (GenSh)
        - Fast generator starts based on operational parameters
        - (GenStart)
        - Intentional islanding in transmission (T-Islanding))
        - Intentional islanding in distribution (D-Islanding)
        - Voltage/var management (VVM)
        - Distributed generation pre-setting (DER)
        - Demand response pre-setting (DR)
        - Electric storage
        - Re-coordination of protection in distribution systems (RPRC)

    b. Real-time remedial action functions
        - Load-shedding
            - Under-frequency Load Shedding (UFLS)
            - Under-voltage Load Shedding (UVLS)
            - Special Load Shedding (predictive)
            - Block Load Shedding (BLS)
            - Interruptible load
        - Generator-shedding
        - Fast generator starts based on operational parameters (angle, voltage, frequency, other)
        - Intentional islanding in transmission
        - Intentional islanding in distribution (micro-grids)
        - Distributed generation starts
        - Demand response enabling
        - Electric storage enabling
        - Transmission sectionalizing
        - Voltage/var management

c. Real-time restorative functions
    - Auto-synchronization
    - Restoration of shed loads (Load)
      – After under-frequency load shedding
      – After under-voltage load shedding
      – After special load shedding
    - Reset of distributed generation (DER)
    - Reset of Demand Response (DR)
    - Reset of electric storage (ES)
    - Reset of VVO objective (VVM)

The following major DMS Applications need coordination with EMS applications:

- Real-time Distribution Operation Model and Analysis
- (DOMA) including Transmission Bus Load Models (BLM)
- Fault Location, Isolation and Service Restoration (FLIR)
- Voltage/Var/Watt Optimization (VVWO)
- Distribution Contingency Analysis (DCA)
- Multi-level Feeder Reconfiguration (MFR)
- Relay Protection Re-coordination (RPRC)
- Pre-arming of Remedial Action Schemes (PRAS)
- Coordination of Emergency Actions (CEmA)
- Coordination of Restorative Actions (CRA)
- Intelligent Alarm Processing (IAP)

Figure 1 illustrates some associations of the EMS applications with the DMS applications.

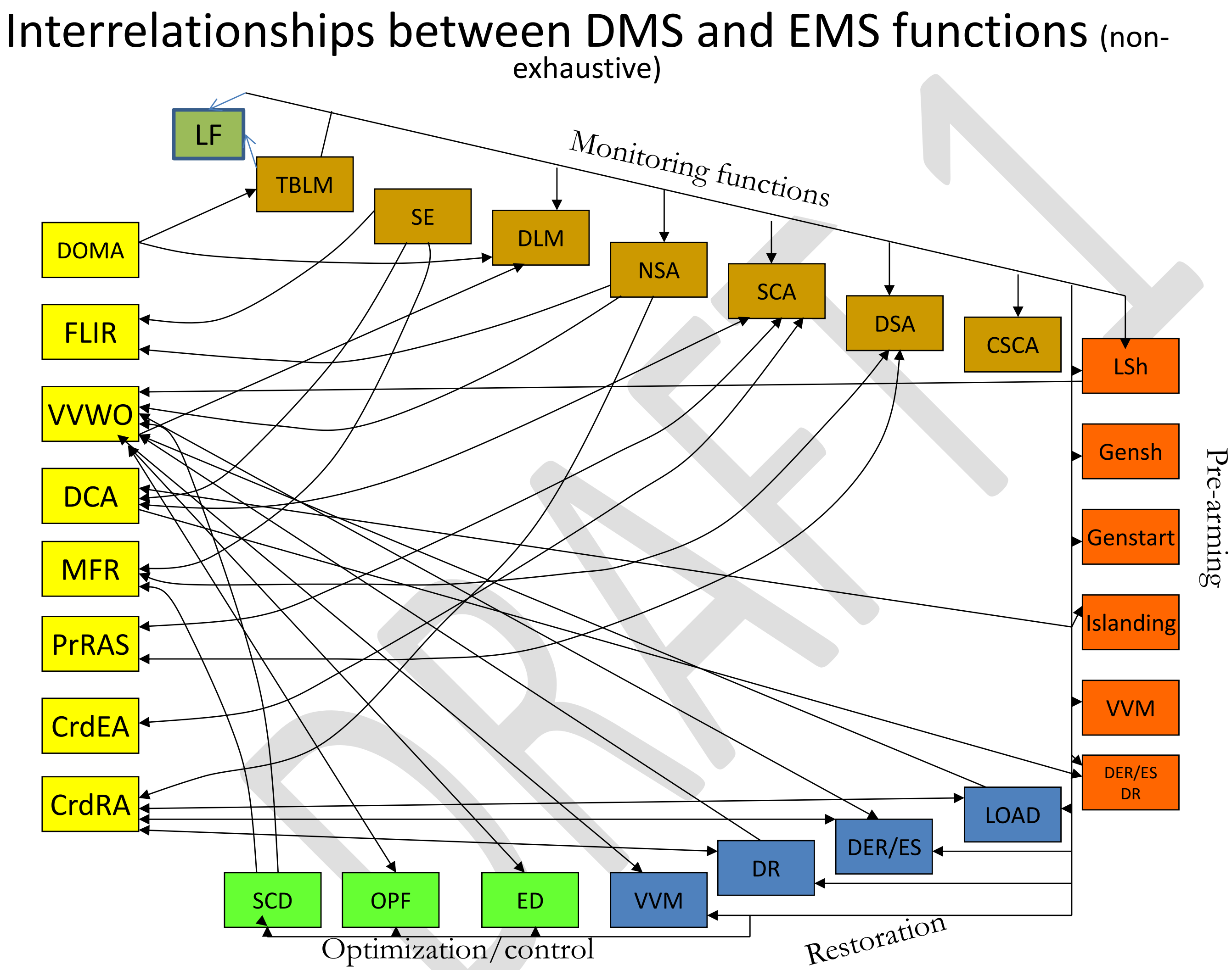


Figure 1. A non-exhaustive illustration of the relationships between the DMS and EMS applications.

1.4.1 Examples of cross-cutting aspects of DMS functions

1.4.1.1 Situational Awareness about the Distribution Operations (based on Distribution Operation Model and Analysis- DOMA)

The DOMA functionality is based on the following component models:

- **Model of transmission/sub-transmission system**. This model is needed to account for the impact of the distribution operations on transmission operations.
- **Model of distribution circuit connectivity**. This model is supported by the GIS database for nominal connectivity and by SCADA and operator's input for real-time updates.
- **Models of distribution circuit facilities**. In addition to the conventional facility models, these models include the models of different kind of controllers and the secondary circuit equivalents.
- **Models of distribution nodal loads**. In the Smart Grid environment, the concept of 'typical' load shape is not applicable due to the diversity of possible behavior of the many distributed generators, electric storage devices, plug-in electric vehicles, and demand response means embedded in many customer loads [9, 10].
- **Models of Distributed Energy Resources and Micro-grids**. As the minimum, the DER models should be sufficient to estimate the generated kW and kvars at any given time, the financial attributes, and the capability curves. These models can be supported by SCADA, Customer Information Systems, DER and AMI data management systems, by aggregators, and by weather forecast systems. The behavioral models of the renewable DER should include the intermittent behavior of these resources. The models of DER and Micro-grids should include the attributes of their controllers.
- **Model of distribution power flow/state estimation**. Under conditions of the Smart Grid, the power flow/state estimation will need to model the price-dependent events, and solve radial and meshed networks with multiple generation busses in different modes of operation.

The analysis part of the DOMA application includes the following analyses:

- **Analysis of adequacy of distribution system operations**. The adequacy of the operations is defined by the loading of the distribution elements, by the reasonability of the voltage drops along the circuits, by the consistency of the fault currents with the capabilities of distribution facilities. The fault analysis should also include the contribution of the DER and should estimate the impact of the fault on the status and operations of the DER.

- **Power quality analysis.** In the Smart Grid environment, this sub-function will analyze the voltage deviations, sags and swells measured and collected by the AMI system, will analyze the correlations between higher harmonic levels and operations of shunt devices and power electronics, including converter-based DER devices.
- **Analysis of the economic efficiency**. The incremental cost may include the cost of supply from both bulk energy sources and distributed energy sources, the incremental cost of demand response incentives, the cost of losses, the penalties for limit violations, etc. The evaluation of the incremental benefits of “what-if” operations can be done by DOMA in the near-real time mode with pre-defined changes calculating the difference between the actual operations and the “what-if” operations.
- **Determining the dynamic T&D bus voltage limits.** The dynamic optimization of the distribution system operations results in different optimum voltages at the distribution side of the T&D substation. These voltages can be supported within a certain range of the transmission-side voltages. This range defines the transmission-side voltage limits at the time of optimization. There may be another set of dynamic voltage limits: the power quality limits, when the voltage at the buses shall satisfy the standard voltage tolerances at the customer terminals. The dynamic voltage limits defined by DOMA should be submitted to the transmission domain for use in the Wide Area Situational Awareness applications.
- **Determining the available dispatchable real and reactive load at the T&D buses**. The significant penetration of DER, Demand Response, and PEVs in combination with Volt/Var/Watt control and Feeder Reconfiguration applications will provide wide ranges of dispatchable loads at the T&D buses. These loads will be dependent on a number of conditions, such as real-time energy prices, reliability signals (can be price also), ancillary service conditions, temporary voltage limit for peak load reduction, weather, etc. Hence, the dispatchable loads at the distribution side shall be also based on adaptable models.
- **Determining the aggregated at the T&D buses parameters of remedial action schemes**. In many cases the actuators for load-shedding Remedial Action Schemes (RAS) are located in the distribution system on per feeder basis. In the future, the load shedding could be done in a more refined manner moving it closer to the end users, e.g., using micro-grids, operating in absorbing mode. The Wide Area Measurement and Control System (WAMCS) should define for each moment the amount of load to be armed at different RAS to satisfy the power security requirements. The DMS application should support the model of available loads under different RAS, their interrelationships, and their behavior under different circumstances.
- **Determining the aggregated load-to-voltage and load-frequency dependences at the transmission/distribution buses.** These dependences are defined by the natural dependences of the end-user loads, by the reactions of the voltage-controlling devices, and by the reactions of the DER protection schemes to the significant changes of the voltage and frequency in the bulk power system. With the significant penetration of the active elements in the ADN, these dependences will become very dynamic and should be updated by a near-real-time application, like DOMA.

A conceptual design of the DOMA application and the sources of information for DOMA support are presented in Figure 2.

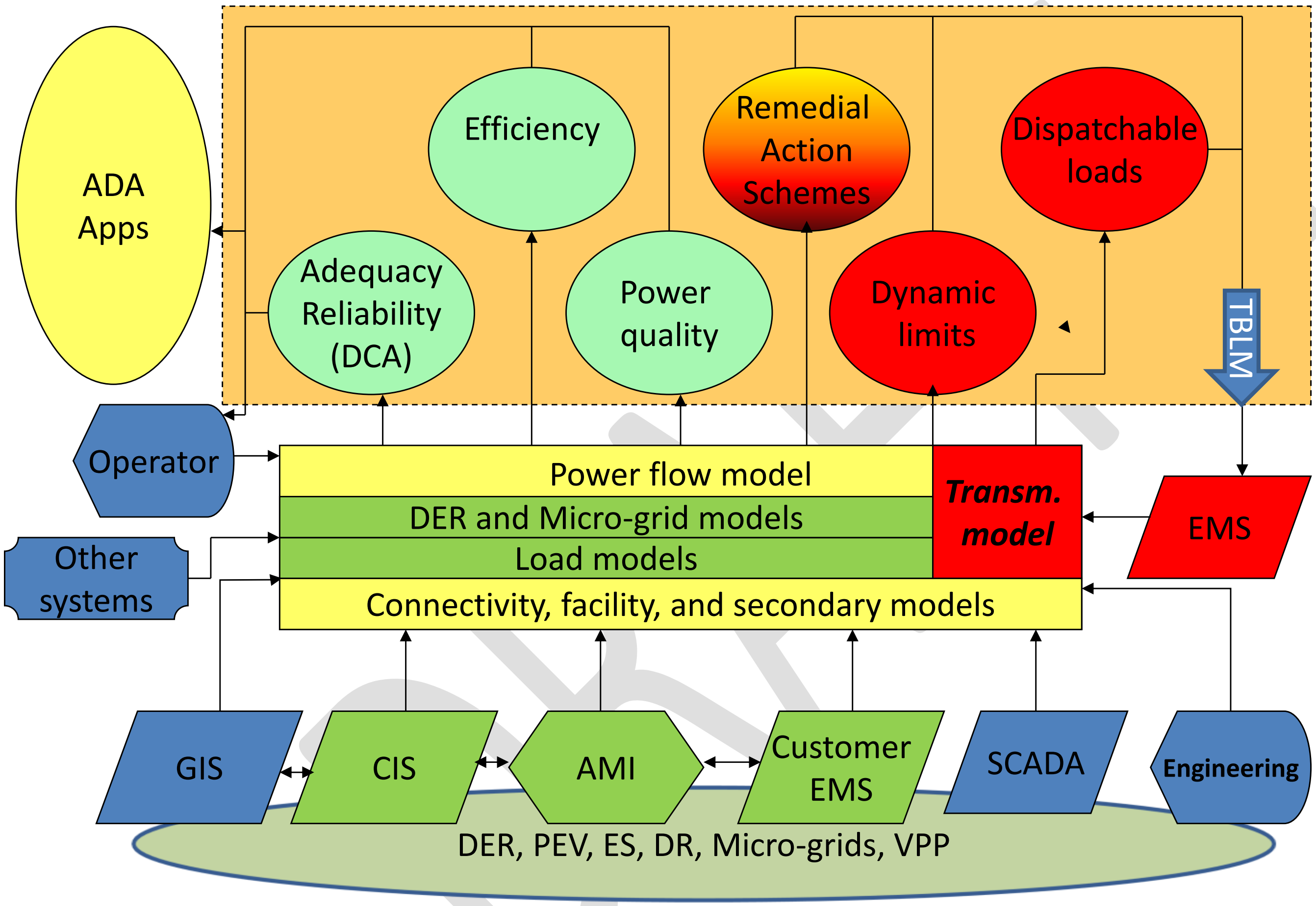


Figure 2. Conceptual design of Situational Awareness for Distribution Operations (DOMA-based)

1.4.1.2 Integrated Voltage, Var, and Watt Optimization (IVVWO)

This is a major multi-objective DMS application performing dynamic optimization of the distribution operations taking into account all significant impacts of the application on the operations in different domains (Figure 2).

The Inter- and Intra-domain Objectives of IVVWC are as follows:

- Ensure standard voltages at customer service terminals
- Reduce load by a given value
- Conserve energy
- Minimize feeder segment(s) overload
- Reduce or eliminate overload in transmission lines
- Reduce or eliminate voltage violations in transmission
- Provide reactive power support for transmission
- Provide spinning reserve support
- Reduce cost of energy
- Reduce energy losses in D&T
- Expand operational tolerances for G/T operations

The Inter and Intra-domain Constraints of IVVWC are as follows:

- Voltage limits at the customer service terminals.
- Voltage limits in selected point of distribution primaries
- Loading limits of distribution elements
- Loading and voltage limits in transmission
- Reactive power or power factor limits in T&D
- Capability limits of DER/ES/DR
- Operating reserve limits

- LTC and VR limits
- Capacitor control limits

The VVWO application calculates the optimal states of the following controllable devices:

- Voltage controller of LTCs
- Voltage regulators
- DER controllers
- Demand Response means
- Controllers of power electronic devices
- Capacitor controllers
- Electric Storage controllers
- Micro-grid controllers

In the Smart Grid environment, in addition to the current control of voltage controller settings and feeder capacitor statuses, the application should be able to control the reactive power of DER and other dynamic sources of reactive power. Under some objectives, the application should be able to control the Demand response means and the real power of DER [8, 9]. Therefore, the Volt/var optimization becomes a Volt/var/Watt optimization.

As seen in the lists of VVWO objectives, constraints, and controls, there are positions related to the customer and to the transmission operation domains.

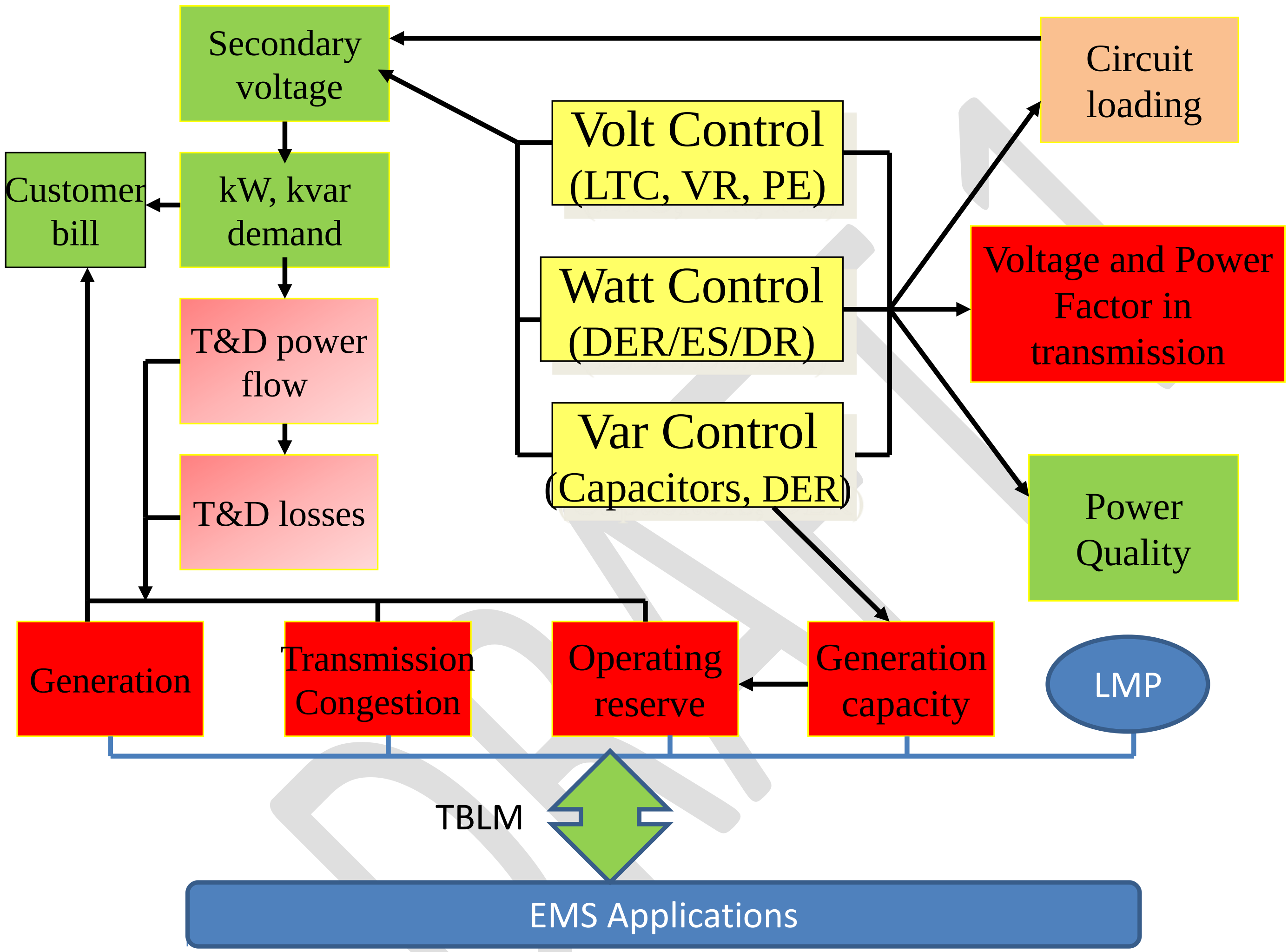


Figure 3. The impact of IVVWO on power system operations

1.4.1.3 Contingency Analysis

With significant penetration of DER, there will be a new kind of contingencies associated with a loss of a significant DER or with a loss of several DERs. The loss of several DERs or Micro-grids may happen due to a significant distortion of the operating conditions in the adjacent transmission systems (Figure 4). IEEE P1547™-2003 defines the voltage and frequency distortions, under which the DER shall be automatically disconnected. These distortions can propagate to a large number of DER connected to the affected distribution system. The disconnection of these DERs may cause overloads and under-voltages in distribution and can worsen the situation in the transmission system.

The cross-cutting aspects of the Distribution Contingency Analysis can be summarized as follows:

- The transmission contingency analyses should define whether the distortion can cause significant disconnection of DERs and reactions of other controlling devices
- Disconnection of these DERs may cause overloads and under-voltages in distribution and can worsen the situation in the transmission system.
- The severity of the contingency also depends on the DER protection settings and on load-generation balance of micro-grids
- Models of the emergency behavior of DER, DR, ES and DMS applications aggregated at the transmission buses should be made available to WAMPAC applications
- The probable distortions of transmission operations should be made available to the DMS for the DCA to assess the possible consequences.

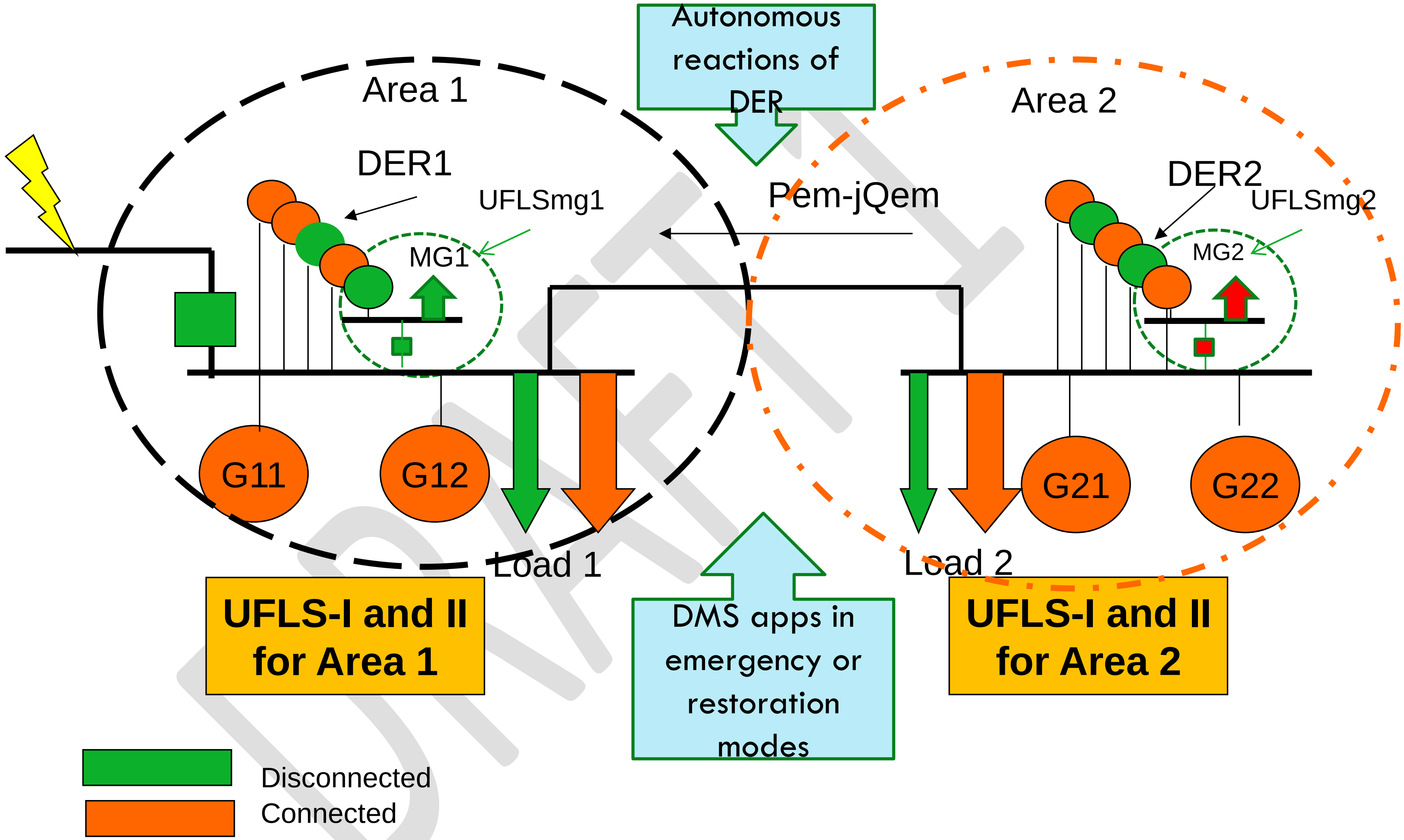


Figure 4. Illustration of the power system and control systems components involved in the Contingency Analysis

1.4.1.4 Fault Location, Isolation and Service Restoration (FLIR)

This application detects the fault, determines the faulted section and the probable location of fault, and recommends an optimal isolation of the faulted portions of the distribution feeder and the procedures for the restoration of services to its healthy portions.

The cross-cutting aspects of the FLIR application are mostly related to the constraints of the applications, including:

- Loading of distribution facilities
- Voltages at customer terminals
- Loading of transmission facilities
- Voltage angle differences for adjacent transmission buses, which depend on transmission operations [10]
- Demand response limitation
- DER operational limitations
- Electric storage discharge limitations

The restoration solutions are based on considerations of the availability of remotely controlled switching devices, availability of feeder paralleling, DER, on creation of intentional islands supported by distributed energy resources, and on transmission loading. The solutions are dynamically optimized based on the expected operating conditions during the time of repair.

1.4.1.5 Multi-level Feeder Reconfiguration (MFR)

This application performs a multi-level feeder reconfiguration to meet one of the following objectives or a weighted combination of these objectives:

- Optimally restore service to customers utilizing multiple alternative sources. The application meets this objective by operating as part of FLIR
- Optimally unload an overloaded segment
- Minimize losses
- Minimize exposure to faults
- Equalize voltages.

- Swap loads to reduce LMPs and assist in congestion management [11,12]

The FLIR and the MFR applications use the results of EMS State Estimation for phase angle differences before paralleling and the energy market prices and the congestion situation before swapping load between buses with different LMPs.

1.4.1.6 Relay Protection Re-coordination (RPR) and Coordination of Emergency Actions (CEmA)

These applications adjust the relay protection settings to real-time conditions based on the preset rules. The following cross-cutting actions will be involved in the performance of these applications:

- The applications will receive pre-arming signals from WAMCS and will change the setups of distribution-side remedial action schemes
- WAMCS applications will take into account
  - the protection settings of the DER and the generation-load balances of micro-grids
  - the available extent and timing of the distribution-side remedial schemes, which should be armed
- CEmA will recognize the emergency situations and will coordinate the objectives, modes of operation, and constraints of other Advanced DMS applications.

1.4.1.7 Coordination of Restorative Actions (CRA)

CRA will coordinate the restoration of services and normal operations based on the availabilities in distribution, transmission, and generation domains after the emergency conditions are fully or partially eliminated.

1.4.2 Examples of EMS applications associated with DMS applications

For normal operating conditions

- Wide Area Situational Awareness (WASA), including
  - Model Updates including the relevant component of the distribution operations, such as
    - ✓ Current bus load
    - ✓ Available dispatchable load

    - ✓ Load dependences on voltage and frequency
    - ✓ State of relevant DMS applications
  - State Estimation (provides voltage angles for MFR and FLIR)
  - Network Sensitivity Analysis, including the sensitivities of distribution components
- Optimal Power Flow, including variables of the distribution domain, such as
  - Dispatchable real and reactive loads
  - Dispatchable distributed real and reactive generation and electric storage
  - Objectives of IVVWO
  - Reallocation of load from buses with higher LMP to buses with lower LMP
- Economic Dispatch, including
  - Virtual Power Plants in distribution
  - Dispatchable distributed generation and electric storage
- Reserve Monitoring , including
  - Virtual Power Plants in distribution
  - Capabilities of distributed generation and electric storage
  - Available Demand Response
  - Dispatchable load via IVVWO
- Other….

For Emergency Operating Conditions

- Steady-state contingency analysis, including reactions to changes in voltage and reliability price signals by
  - Regular loads in distribution (without DR)
  - DER and electric storage
  - Demand Response

- DMS applications

- Dynamic security analysis including reactions to changes in voltage, frequency, and reliability price signals by
  - Regular loads in distribution
  - DER and electric storage
  - Demand Response
  - DMS applications
- Security Constrained Dispatch including variables of the distribution domain, such as
  - Dispatchable real and reactive loads
  - Dispatchable distributed real and reactive generation and electric storage
  - Objectives of IVVWO
  - Reallocation of load from buses with higher LMP to buses with lower LMP
- Near Real-time Pre-arming including presetting of distribution components, such as
  - Remedial Action Schemes in distribution
  - Intentional islanding in distribution
  - Voltage, var, and power flow controlling functions
  - Protection of distributed generation pre-setting
  - Demand response triggers
  - Electric storage triggers
  - Re-coordination of protection in distribution systems
- Remedial Actions, including distribution components, such as
  - Load-shedding
  - Intentional islanding (micro-grids)
  - Distributed generation starts

    - Demand response activations
    - Electric storage activation
    - Voltage, var, and power flow control in emergency modes.
- Service restoration, including distribution components, such as
    - Restoration of loads shed by load–shedding schemes.
    - Reset/re-synchronization of distributed generation
    - Reset of Demand Response
    - Reset of electric storage
    - Reset of VVWO objective

For post-factum analysis collection of information on significant events in distribution will be needed.

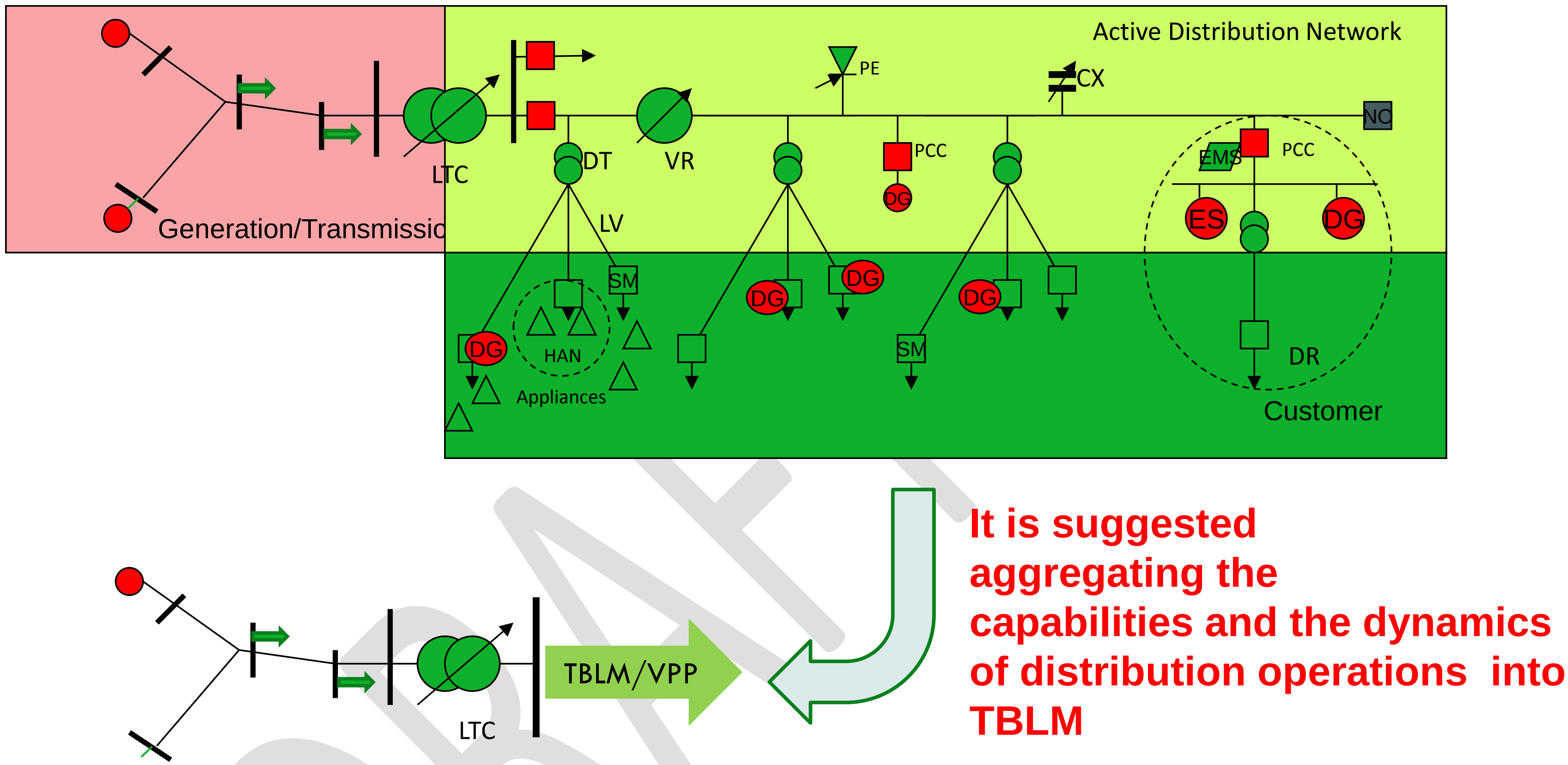


Figure 5. Power system domains involved in the TBLD

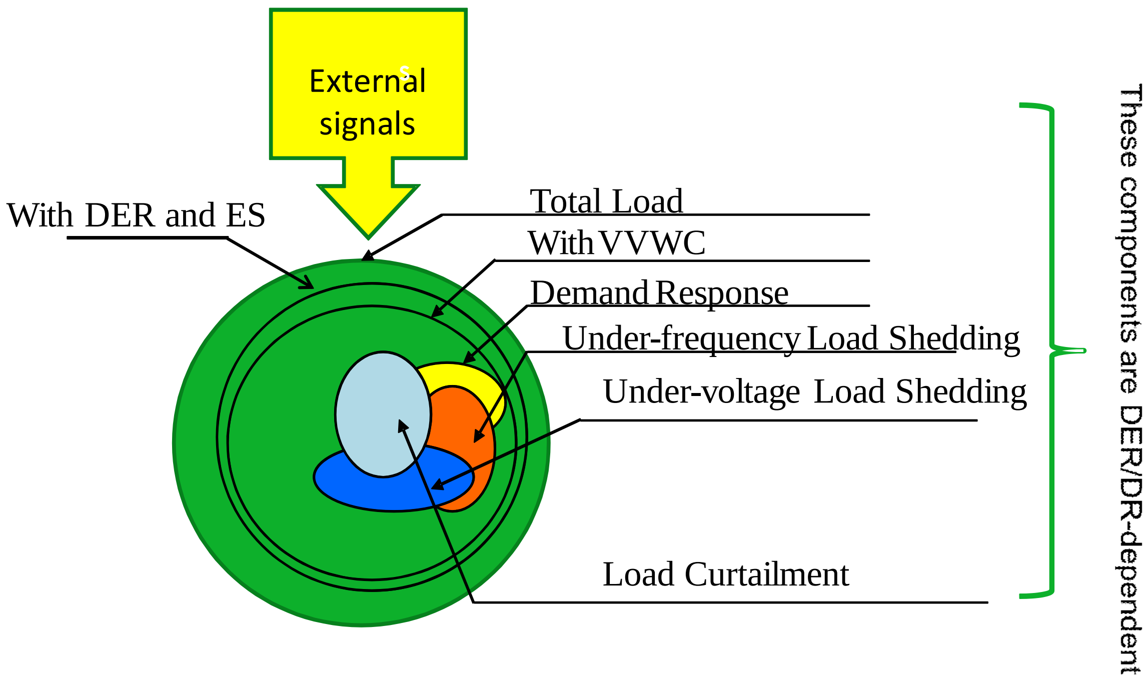
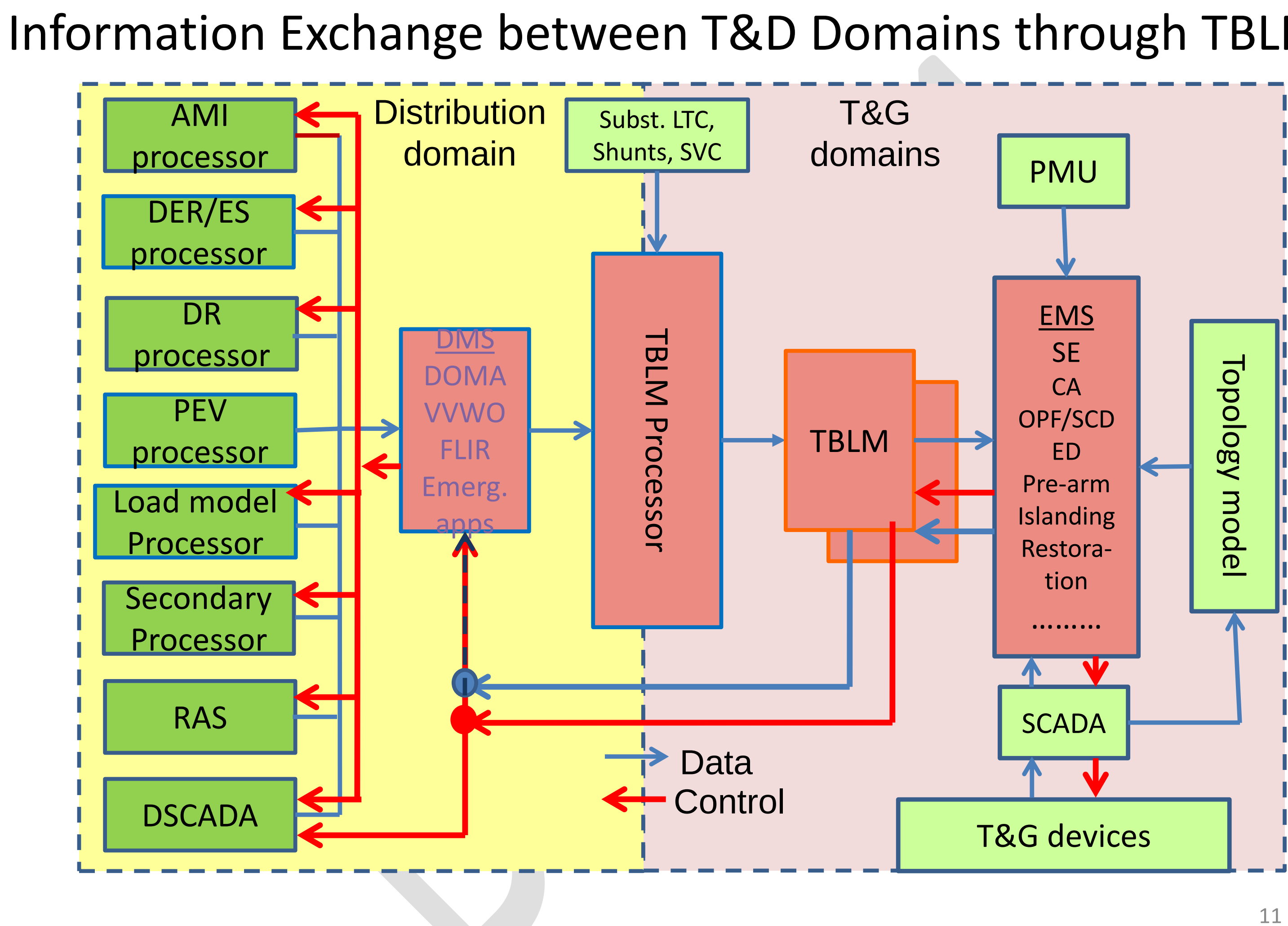


Figure 6. Load Model components

- ○ Other components of TBLM

- VPP technical and economic functions and attributes

- Aggregated capability curves
- Aggregated real and reactive load-to-voltage dependencies
- Aggregated real and reactive load-to-frequency dependencies
- Aggregated real and reactive load dependencies on
  - Demand response control signals,
  - Dynamic prices,
  - Weather, etc.
- Aggregated dispatchable load
- Model forecast
- Overlaps of different load management functions, which use the same load under different conditions.
- Ownership of loads (jurisdiction, related to regulatory issues)
- Ownership of DER, ways of controlling (jurisdiction, related to regulatory issues)
- Degree of uncertainty…..



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2 **Figure 7. Information infrastructure for development of TBLM**

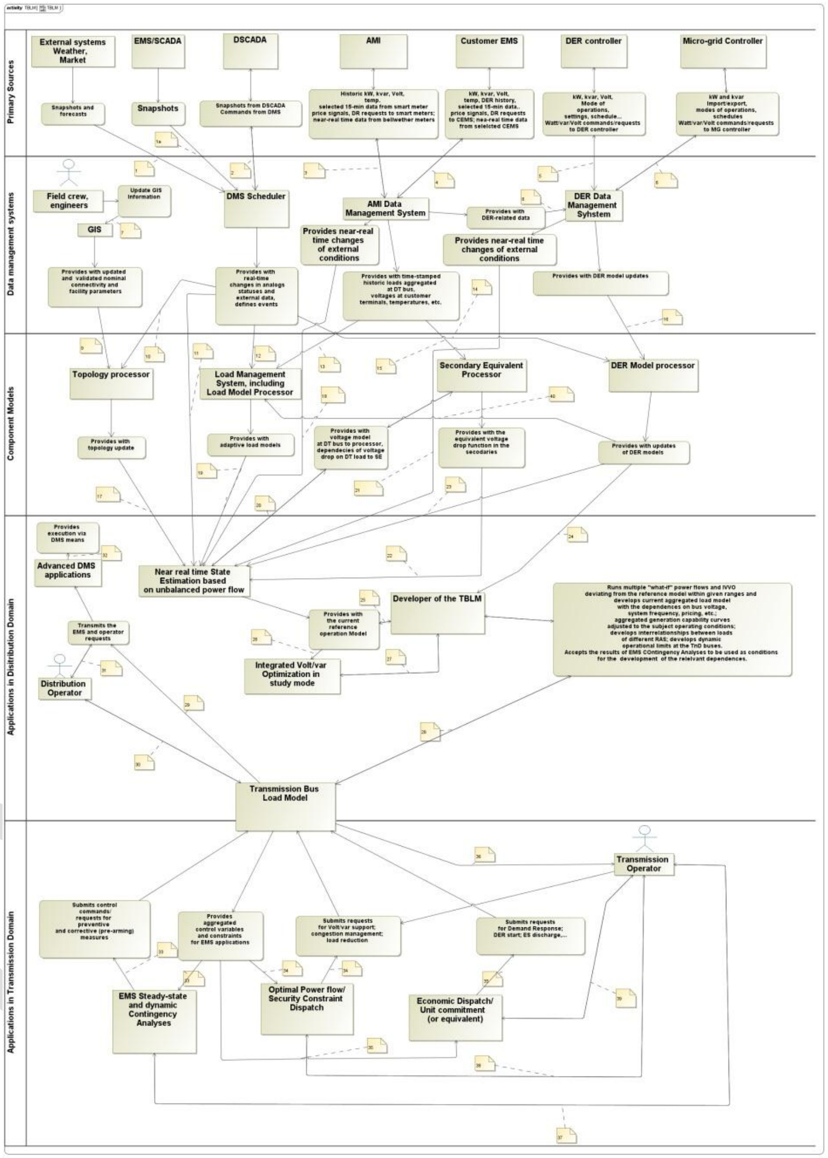


Figure 8. Activity Diagram

Conclusions

- The EMS and DMS applications for Smart Transmission and Distribution grids are tightly interrelated, and they should be functionally integrated to provide the needed security and efficiency of power system operations.
- To make the dynamic optimization manageable in a holistic manner, **decompositions** of the operational models of each domain should be used, and **aggregated information exchange** between the domains should be provided
- ➢ The concept of the aggregated Distribution Operation Models at the Transmission buses (TBLM) is suggested so meet these requirements.
- ❑ The **sophistication** of the TBLM and the Smart Grid applications should match the **complexity** of the processes in power systems to achieve maximum benefits.

2 Actor (Stakeholder) Roles

Describe all the people (their job), systems, databases, organizations, and devices involved in or affected by the Function (e.g. operators, system administrators, technicians, end users, service personnel, executives, SCADA system, real-time database, RTO, RTU, IED, power system). Typically, these actors are logically grouped by organization or functional boundaries or just for collaboration purpose of this use case. We need to identify these groupings and their relevant roles and understand the constituency. The same actor could play different roles in different Functions, but only one role in one Function. If the same actor (e.g. the same person) does play multiple roles in one Function, list these different actor-roles as separate rows.

Table 1. Actors

Actor Name	*Actor Type (person, organization, device, system, or subsystem)*	*Actor Description* *Functionality related to TBLM*
Primary Sources of information		
• DER controller	Device	Measures, stores and communicates current generation, generation schedules, capability curves, protection settings, mode of operations and voltage/var control settings, and other data needed for current and predictive model of DER operations Communicates with DER Data Management System or other systems dedicated to manage DER and with DA applications. Supports control of frequency and voltages if included in an intentionally created electric island.
• Micro-grid Controller	Device	Calculates, stores, and communicates aggregated load, Demand Response, Generation data for the Micro-grid, Protection settings and settings for frequency and voltage control for connected and for autonomous modes of operations, other data needed for current and predictive model of Micro-grid operations. Communicates with Data Management System or other systems dedicated to manage Micro-grids and with DA applications. Supports control of frequency and voltages in autonomous mode of operations.

• AMI meters	Devices	Advanced electric revenue meter capable of two-way communications with the utility. Serves as a gateway between the utility, customer site, and customer's load controllers. Measures, records, displays, and transmits data such as energy usage, generation, text messages, and event logs to authorized systems and provides other advanced utility functions. Measurements and storage of: kW and kvar kWh Load profiles Interval average voltages Instantaneous voltages Instantaneous frequency Weather data. Services: Last Gasp/AC Out Demand Response functions Information for customers and third parties Communications with HAN
• External systems Weather, EMS…	Systems	Public information systems outside the utility, provides the utility with information on weather and major event relevant to utility operations. The information obtained from these systems is used by the modeling components of ADA for adjustment of the behavioral models. This information is most important for the development of the models of weather-dependent DERs.

Aggregator/ Energy Services Company	Company	A person or company combining two or more customers into a single purchasing unit to negotiate the purchase of electricity from retail electric providers, or the sale to these entities. The transaction may include electricity consumption and demand, DER/Micro-grid generation, Demand Response "Nega-watts", and ancillary services. Aggregators also combine smaller participants (as providers or customers or curtailment) to enable distributed resources to play in the larger markets. The agreement between the customers and the Aggregators, if approved by the utility, define the conditions under which the DERs will operate during pre-defined times, and the operational tolerances for control of these devices, if any.
• DSCADA	System	DSCADA collects data from IEDs beyond the fence of the T&D substation and supports remote control of controllable devices in the field either in supervisory or close-loop modes. The field IEDs include utility DER and Micro-grid controllers, may include customer EMS. Distribution SCADA database is a major source of input data for the ADA applications. It is updated via remote monitoring and operator inputs. DSCADA is used for execution of ADA application solutions either in supervisory, or in close-loop modes.

• Customer EMS	Local system	A customer supplied system for monitoring and managing energy use at their residence or business. It includes human interface displays for interacting with the system and allows the customer to program functions, control loads, and display energy costs, usage, and related information. It can be programmed to take action based upon price inputs or event messages from the utility, or changes to customer's load. Interfaces with HAN devices and the Smart Meter Measurements and storage of aggregated data from Smart Meters: kW and kvar kWh Load profiles Interval average voltages Instantaneous voltages Instantaneous frequency Weather data. Services: DER monitoring and control functions Demand Response functions Information for customers and third parties Communications with HAN and Smart Meters
• Field Crew	Persons	Personnel assigned to collect missing and new data for updating GIS The field crew reads and transmits nameplate data from equipment when performing work in the field
Data management systems		

• GIS	System	Repository of distribution system assets, their relationships (connectivity), ownerships, nominal states, and links to associated objects. AM/FM system contains the geographical information of the distribution power system circuit connectivity, as well as the parameters describing the power system facilities, including all electric characteristics of distribution transformers, as well as circuit connectivity and parameters of secondary circuits between the distribution transformers and customers or their equivalents consistent with voltage drops and power losses. Conceptually, the AM/FM/GIS database can contain transmission connectivity and facility data and relevant to distribution operations customer-related data. AM/FM/GIS databases is interfaced with the Customer Information System for linkage between the customer data and point of connection, with AMI, DER, and DR data management systems for updates of secondary circuit equivalents, and behavioral models of load, DER, ES, and DR. Alternative interfaces between these data management systems and ADA are possible. AM/FM/GIS databases are also accessible to field crews via mobile computing for updates on facility connectivity and parameters. The AM/FM/GIS databases shall be updated, proof-tested and corrected in a timely manner to provide a high probability of preparedness for supporting near-real-time ADA applications.
• DER Data Management System	System	A specific database for DER attributes, behavioral models, contracts, and performance associated with the owner. DER data management system is interfaced with AMI data management system, Aggregators, with the Load Management System, and with the ADA applications providing DER behavioral models.

• DMS Scheduler	Sub-System	Computer-based system consisting of Graphic User Interface, interface with distribution SCADA, and ADA applications Accepts, checks, and organizes information obtained from DSCADA, Operators and external systems and triggers ADA applications according to the given setups. Accepts output information from ADA applications and initiates execution of their instructions.
• AMI Data Management System	System	Gathers, validates, estimates, and permits editing of meter data such as energy usage, generation and meter logs. Stores this data for a limited amount of time before it goes to the Meter Data Warehouse and makes the data available to authorized systems. Includes load model processor and secondary equivalent processor. Derives aggregated at the distribution transformer load profiles Communicates either directly or through a network Management system with the Smart meters Communicates with DA applications Provides ADA with behavioral load models.
Component Models		
• Secondary Equivalent processor	Software program	Provides DMS with equivalents of the voltage drops and power loses in the secondary circuits fed from distribution transformers Derives the voltage drop and the power loss equivalents in the secondaries as functions of the available near-real time data, based on the historic AMI data and modeled or measured voltages at the LV bus of the distribution transformers.
• DER Model processor	Software program	Provides DMS with full object model of DER Derives the object model from the data obtainable from the DER controller, DER Data Management System, historic measurements and external data.

• Load Management System, including Load Model Processor	Software program	Provides DMS with adaptable distribution nodal load models, including load dependencies on voltage, frequency, price, weather, etc., and the load association with load management means, such as DR, Load shedding schemes, blackout conditions, etc. Derives adaptable load models from historic AMI and external data
• Topology processor	Software program	Provides DMS with near-real time connectivity model Derives and validates the connectivity model based on GIS, DSCADA data and on validation power flow analysis
Actors in Distribution Domain		
• Advanced DMS applications	Computing applications	Set of DMS applications in near-real time and study modes Supports "what if" contingency scenarios for the expansion of the TBLM beyond the near-real time timeframe
• Distribution Operation Model and Analysis (DOMA), based on near real time Distribution State Estimation	Computing application	It runs periodically and by event; models near real-time power flow; Provides situational awareness of distribution operations; Provides background models for other ADA applications. Utilizes behavioral nodal load, DER Micro-grid, and PV models and secondary equivalents. Communicates with AMI, DER, and DR data management systems. Determines the near-real time operating conditions that impact the load models and the dynamic operational limits, including the bus voltage limits and DER capability curves. Is supported by a database, which is updated by relevant changes.

• Developer of the TBLM	Computing application	Provides the aggregated transmission bus model, including: Load components; VPP technical and economic functions and attributes; Aggregated capability curves; Aggregated real and reactive load-to-voltage dependencies; Aggregated real and reactive load-to-frequency dependencies; Aggregated real and reactive load dependencies on Demand response control signals, Dynamic prices, Weather, etc.; Aggregated dispatchable load; Model forecast; Overlaps of different load management functions; Degree of uncertainty. Derives the aggregated current states and the dependences of the model attributes on the impacting factors retrieved from the real-time measurements and from the DMS applications in near-real time and study modes.
• Integrated Volt/var Optimization in study mode	Computing application	Supports "what if" volt/var control scenarios
• Distribution Operator	Person	Person in charge of distribution operations during the shift The operator sets up the ADA applications, defining the objectives, the modes of operations, the contents of application results presented to the operator, provides certain input data, monitors the results of ADA applications, requests additional information, when needed, authorizes the ADA recommendations, makes decisions based on ADA recommendations, etc. Normally, the operator defines the options for the close-loop control in advance, but does not take a part in the close-loop control.

• Transmission Bus Load Model	Data model	Provides relevant information about distribution operations and resources aggregated at transmission bus. Provides distribution operator and DMS applications with data and requests from transmission operator and EMS applications Serves as a gateway for information exchange between distribution and transmission domains, providing decomposition and, at the same time, integration of EMS and DMS applications.
Actors in Transmission Domain		
• Transmission Operator	Person	Person in charge of transmission operations during the shift The operator sets up the EMS applications, defining their objectives, provides certain input data, monitors the results of EMS applications, authorizes the requests to DMS, makes decisions based on DMS dynamic limits,
• EMS Steady-state and dynamic Contingency Analyses	Computing applications	Develops and analyses a number of transmission contingency analyses Takes into account the dependences provided by TBLM and requests, if needed, actions by DMS, based on the availabilities provided by TBLM
• Optimal Power flow/ Security Constraint Dispatch	Computing applications	Develops optimal solutions for normal transmission operations Takes into account the dependences provided by TBLM and requests, if needed, actions by DMS, based on the availabilities provided by TBLM
• Economic Dispatch/ Unit commitment (or equivalent)	Computing applications	Develops optimal solutions for energy supply Takes into account the dependences provided by TBLM and requests, if needed, actions by DMS based on the availabilities provided by TBLM.

3 Information exchanges

Table 2. Information exchanges

#	# in the SD	Source	Recipient	Contents of information	Volume	Timing	Accuracy
1		External Systems, including SCADA/EMS	DMS Scheduler	Environmental data by locations; Other information impacting the behavior of the customer loads; Analog and statuses from the transmission domain; Protection and Remedial Action Schemes data	Medium to Large	Periodically and by significant changes.	
2		DSCADA	DMS Scheduler	Near real-time analog and status information from the observable portions of the distribution power system Protection and Remedial Action Schemes data	Medium to Large	Minimum exchange times	According to efficient utilization
2		DMS Scheduler	DSCADA	Control commands from ADA applications executable by DSCADA	Small to Medium	Minimum exchange times	
3		Smart Meter/AMI	AMI Data Management System (including Last Gasp service)	kW and kvar kWh Load profiles Interval average voltages Weather data Demand response triggers received with timestamps; Commands issued for Demand Response (thermostat, appliances, DER, Storage).	Large	Once a day	Revenue accuracy for kW and kvar; 0.5%-0.2% accuracy for Voltages
3		Bellwether Smart Meter/AMI	AMI Data Management System	Instantaneous kW and kvar Weather data Instantaneous voltages Instantaneous frequency from dedicated meters in autonomous mode of Micro-grid	Small to average	Last gasp - immediately from selected first-reporters; Instantaneous voltages within	0.5%-0.2% for Volt; 0.1% for Hz

				Last Gasp/AC Out		minutes after fault; Instantaneous frequency from dedicated meters – report by exception	
3		AMI Data Management System	Smart Meter/AMI	Real-time prices Demand response triggers and amount Data requests	Small to average	Immediately after change	
4		Customer EMS	AMI Data Management System	Aggregated from Smart Meters: kW and kvar kWh Load profiles Interval average voltages Weather data. Demand response triggers received with timestamps; Commands issued for Demand Response (customers' Smart Meters, thermostat, appliances, DER, Storage). Protection and Remedial Action Schemes data	Small to average	Once a day	Revenue accuracy for kW and kvar; 0.5%-0.2% accuracy for Voltages
4		Customer EMS	AMI Data Management System (including Last Gasp service)	Lowest instantaneous voltages from included Smart Meters Instantaneous frequency Last Gasp/AC Out from selected Smart Meters	Small to average	Last gasp - immediately from selected first-reporters; Instantaneous voltages within minutes after fault; Instantaneous frequency – report by exception	0.5%-0.2% for Volt; 0.1% for Hz
4		AMI Data Management System (including Last	Customer EMS	Real-time prices Demand response triggers and	Small to average	Immediately after change	

		Gasp service)		amount (Demand response can be executed via load reduction, or DER/ES generation increase, or both) Data requests			
5		DER &Controller	DER Data Management System	Generation kW and kvar Generation kWh Generation profiles Interval average voltages Weather data. Generation change triggers received with timestamps; Active protection settings and mode of operations and settings for volt/var control in the connected mode of operations and voltage and frequency control settings for island mode of operations, settings for ride-through operations Capability curve Electric storage parameters Synchronization settings O&M cost functions	Small to average	Once a day	Revenue accuracy for kW and kvar; 0.5%-0.2% accuracy for Voltages
5		DER &Controller	DER Data Management System	Lowest instantaneous voltages before disconnection Instantaneous frequency in island mode Last Gasp/AC Out or protection actions Changes in relay protection settings, volt/var control modes and settings, ride-trough settings, electric storage parameters	Small	Immediately after change	0.5%-0.2% for Volt; 0.1% for Hz
5		DER Data Management	DER &Controller	Real-time prices	Small	Immediately after	

		System		Desired kW and kvar setpoints (reference points) Desired volt/var mode of operation and setpoints Desired ride-through settings Data requests Synchronization commands		change	
6		Micro-grid interconnection controller in PCC	DER Data Management System	Aggregated for Micro-grid net load and generation of kW and kvar Net, load and generation kWh Net, load and generation load profiles Interval average voltages from selected Smart Meters Weather data. Demand response triggers received with timestamps; Commands issued for Demand Response (customers' Smart Meters, thermostat, appliances, DER, Storage) Protection settings and settings for frequency and voltage control for connected and for autonomous modes of operations, Operational limits O&M cost functions Other data needed for current and predictive model of Micro-grid operations, e.g., electric storage parameters, load-shedding RAS parameters.	Small to average	Once a day	Revenue accuracy for kW and kvar; 0.5%-0.2% accuracy for Voltages
6		Micro-grid interconnection controller in PCC	DER Data Management System	Lowest instantaneous voltages from included Smart Meters Instantaneous frequency Last Gasp/AC Out from	Small to average	Last gasp - immediately from selected first-reporters;	0.5%-0.2% for Volt; 0.1% for Hz

				selected Smart Meters Changes in relay protection and RAS settings, volt/var control modes and settings, ride-trough settings, and electric storage parameters.		Instantaneous voltages within minutes after fault; Instantaneous frequency – report by exception in autonomous mode of operations. Changes - immediately	
6		DER Data Management System	Micro-grid interconnection controller in PCC	Real-time prices Demand response triggers and amount Disconnection command for intentional islanding Desired kW and kvar setpoints Desired voltage setpoints Data requests	Small to average	Immediately after change	
7		Field Crew	GIS	States and parameters of the corresponding equipment observed in the field according to pre-defined instructions (template)	Small	During the presence at the subject in the field	Verified information
8		AMI Data Management System	DER Management System	Provides the DER Management System with relevant data on customer owned/embedded DER	Average to large	Once a day and by defined events	
9		GIS	Topology processor	Provides with updated and validated nominal connectivity and facility parameters	Small to average, if incrementally; Large, if globally	One a day, and by significant events	Verified data
10		DMS Scheduler	Topology processor	Provides with real-time changes in topology	Small	Immediately after change	Verified data
11		DMS Scheduler	State estimator	DSCADA/SCADA/EMS analog and status snapshots;	Medium to Large	1-2 seconds updates	Verified data

12		DMS Scheduler	Load model processor	Provides with real-time changes in analogs and external data related to adaptive load modeling, e.g., weather and prices	Small to Medium	Periodically every 5-15 minutes and by defined events	
13		AMI Data Management System	Load model Processor	kW and kvar profiles for every day Impacting factors with time stamps Local weather data Demand response with start and stop times Other related events with timestamps	Large	Once a day	Verified historic data
14		DMS Scheduler	DER model processor	Provides analogs and external data relevant to DER operation modeling, e.g., weather parameters, prices, DR requests, etc.	Average	Periodically and by events	Verified data
15		AMI Data Management System	Secondary Equivalent processor	Daily kW and kvar load profiles from individual Smart meters and aggregated at the distribution transformer load profiles Daily profiles of interval-average voltages	Large	Once a day	
16		DER Management System	DER model processor	Provides with updates on DER parameters relevant for DER modeling	Small to average	One a day and by events	Verified data
17		Topology processor	State estimator	Provides with topology updates	Small	By event	Verified data
18		AMI Data Management System	Distribution power flow/state estimation	Provides with near-real time changes of external conditions	Small	By event. This information is based on the input from bellwether meters monitoring local weather and sunshine conditions	Verified data
19		Load model Processor	State estimator	List of nodes in clusters	Average	Once a day	

				Name of clusters Representative nodal load models for clusters of similar loads			
20		State estimator	Secondary Equivalent processor	Modeled voltages at the secondary buses of distribution transformers	Large	On request by Secondary Equivalent processor (once a month or less frequent)	
21		DER Data Management System	State estimator	Provides with near-real time changes of external conditions for DER operations.	Average	By event. This information is based on the input from selected DER monitoring local weather and sunshine conditions	
22		Secondary Equivalent processor	State estimator	Provides with dependencies of voltage drops and losses in secondaries on nodal loads	Large		
23		DER model processor	State Estimator	Provides with updates of DER models	Average	After significant change (once a month or less frequent)	
24		DER model processor	Developer of TBLM	Provides with updates of DER models	Average	This information exchange is needed if the DPF/SE routine is a part of the TBLM developer	
32		DMS applications	DMS execution means	Provides execution via DMS means	Small	After DMs applications run and determine a need in control	Verified information
29		Transmission Bus Load Model	Advanced DMS applications	Transmits the EMS requests	Small	After EMS application run and determine a need in support from DMS	Verified information

31		Distribution Operator	Advanced DMS applications	Transmits Operator’s requests, changes to EMS requests, etc.	Mall	As needed for a portion of EMS requests,	Verified information
26		Near real time State Estimation based on unbalanced power flow	Integrated Volt/var Optimization in study mode	Provides with the current reference operation model components	Large	Every run of State Estimation and IVVO, e.g., every 5-10 min and by events	Verified information
25		Near real time State Estimation based on unbalanced power flow	Developer of the TBLM	Provides with the current reference operation Model	Large	Every run of State Estimation, e.g., every 5-10 min and by events	Verified information
27		Integrated Volt/var Optimization in study mode	Developer of the TBLM	Provides with the results of IVVO studies based in required changes of operating conditions and their ranges.	Large	Every update of the State Estimation, e.g., every 5-10 min and by events, for multiple scenarios	Verified information
27		Developer of the TBLM	Integrated Volt/var Optimization in study mode	Requests a series of runs for different operating conditions, e.g., within and beyond the LTC capabilities to adjust distribution bus voltage according to current setting; for load reduction objective, etc.	Small	When there is a change in the requirements	
28		Developer of the TBLM	Transmission Bus Load Model	Runs multiple "what-if" power flows and IVVO deviating from the reference model within given ranges and develops current aggregated load model with the dependences on bus voltage, system frequency, pricing, etc.; aggregated generation capability	Large	Every update of the State Estimation, e.g., every 5-10 min and by events, for multiple scenarios	Verified information

				curves adjusted to the subject operating conditions; develops interrelationships between loads of different RAS; develops dynamic operational limits at the TnD buses,...			
28		Transmission Bus Load Model	Developer of the TBLM	Delivers results of steady-state and Dynamic EMS Contingency Analyses	Small	Every run of the EMS CA	
30		Transmission Bus Load Model	Distribution Operator	Informs the operator about the changes in TBLM	Small	As needed based on pre-defined criteria	
30		Distribution Operator	Transmission Bus Load Model `	Authorizes and/or changes the components in the TBLM	Small		
33		Transmission Bus Load Model	EMS Steady-state and dynamic Contingency Analyses	Provides aggregated control variables and constraints for EMS applications	Small	After every update of TBLM	Verified information
33		EMS Steady-state and dynamic Contingency Analyses	Transmission Bus Load Model	Submits control commands/ requests for preventive and corrective (pre-arming) measures	Small	When preventive and corrective measures in distribution are needed	Verified information
34		Transmission Bus Load Model	Optimal Power flow/ Security Constraint Dispatch	Provides aggregated control variables and constraints for EMS applications	Small	After every update of TBLM	Verified information
34		Optimal Power flow/ Security Constraint Dispatch	Transmission Bus	Submits requests for Volt/var support; congestion	Small	When Volt/var support; congestion management in	Verified information

			Load Model	management; load reduction		distribution are needed	
35		Transmission Bus Load Model	Economic Dispatch/ Unit commitment (or equivalent)	Provides aggregated control variables and constraints for EMS applications	Small	After every update of TBLM	Verified information
35		Economic Dispatch/ Unit commitment (or equivalent)	Transmission Bus Load Model	Submits requests for Demand Response; DER start; ES discharge,...	Small	When Demand Response; DER start; ES discharge in distribution are needed	Verified information
36		Transmission Bus Load Model	Transmission Operator	Informs about aggregated control variables and constraints for EMS applications	Small	After every update of TBLM	Verified information
36		Transmission Operator	Transmission Bus Load Model	Changes conditions or submits its own requests for DMS support	Small	In special cases. Typically, the operator is not in the loop of automated control	
37		EMS Steady-state and dynamic Contingency Analyses	Transmission Operator	Informs about submitted control commands/requests for preventive and corrective (pre-arming) measures	Small	When preventive and corrective measures in distribution are needed	Verified information
37		Transmission Operator	EMS Steady-state and dynamic Contingency Analyses	Authorizes or changes the submitted control commands/requests for preventive and corrective (pre-arming) measures	Small	Authorization of EMS requests by the operators can be based on predefined criteria outside of the control loop. In rare cases, the operator may intervene with changes	Verified information

38		Optimal Power flow/ Security Constraint Dispatch	Transmission Operator	Informs about the submitted requests for Volt/var support; congestion management; load reduction	Small	When Volt/var support; congestion management in distribution are needed	Verified information
38		Transmission Operator	Optimal Power flow/ Security Constraint Dispatch	Authorizes or changes the submitted requests for Volt/var support; congestion management; load reduction	Small	Authorization of EMS requests by the operators can be based on predefined criteria outside of the control loop. In rare cases, the operator may intervene with changes	Verified information
39		Economic Dispatch/ Unit commitment (or equivalent)	Transmission Operator	Informs about the submitted requests for Demand Response; DER start; ES discharge,...	Small	When Demand Response; DER start; ES discharge in distribution are needed	Verified information
39		Transmission Operator	Economic Dispatch/ Unit commitment (or equivalent)	Authorizes or changes the submitted the submitted requests for Demand Response; DER start; ES discharge,...	Small	Authorization of EMS requests by the operators can be based on predefined criteria outside of the control loop. In rare cases, the operator may intervene with changes	Verified information
40		DER Model processor	load management system	Updates the information on load management means	Small	Submits to the LMS the IDs of load management switching devices including the ID of the load management types and settings; nodes ID of participants in	

						individual load management , like DR.	

Step by Step Analysis of Function

Describe steps that implement the function. If there is more than one set of steps that are relevant, make a copy of the following section grouping (Steps to implement function, Preconditions and Assumptions, Steps normal sequence, Post-conditions) and provide each copy with its own sequence name.

4 Steps to implement function – Development of TBLM

Preconditions and Assumptions

Describe conditions that must exist prior to the initiation of the Function, such as prior state of the actors and activities
Identify any assumptions, such as what systems already exist, what contractual relations exist, and what configurations of systems are probably in place
Identify any initial states of information exchanged in the steps in the next section. For example, if a purchase order is exchanged in an activity, its precondition to the activity might be 'filled in but unapproved'.

Table 3. Preconditions

Actor/System/Information/Contract	*Preconditions or Assumptions*
Actor/System/Contract	Preconditions or Assumptions
Distribution SCADA	Distribution Supervisory Control and Data Acquisition (SCADA) database is updated via remote monitoring and operator inputs. Required scope, speed, and accuracy of real-time measurements are provided, supervisory and closed-loop control is supported, and their availability is reported. Distribution SCADA communicates with substation Remote Terminal Unit (RTU) controllers, field Intelligent Electronic Devices (IEDs), large Distributed Energy Resources (DER) and micro-grid controllers, and with large Customer

Actor/System/Information/Contract	*Preconditions or Assumptions*
	Energy Management Systems (CEMS).
AM/FM/GIS databases	Automated Mapping/Facilities Mapping (AM/FM) system contains the geographical information systems (GIS) information of the distribution power system circuit connectivity, as well as the parameters describing the power system facilities, including all electric characteristics of distribution transformers, as well as circuit connectivity and parameters of secondary circuits between the distribution transformers and customers or their equivalents consistent with voltage drops and power losses. Conceptually, the AM/FM/GIS database can contain transmission connectivity and facility data and relevant to distribution operations customer-related data. AM/FM/GIS databases is interfaced with the Customer Information System and/or with Advanced Metering Infrastructure (AMI) Data management System for linkage between the customer data and point of the distribution nodal load models, with AMI, DER, and Demand Response (DR) data management systems for updates of secondary circuit equivalents, and adaptable models of load, DER, Energy Storage (ES), and DR. Alternative interfaces between these data management systems and Distribution Management System (DMS) are possible. AM/FM/GIS databases are also accessible to field crews via mobile computing for updates on facility connectivity and parameters. The AM/FM/GIS databases are updated, proof-tested and corrected in a timely manner to provide a high probability of preparedness for supporting near-real-time DMS applications.
AMI	There is a significant penetration of multi-functional Smart Meters able to frequently measure, store, and transmit kW, kvar, high accuracy Volts, voltage sags and swells, "Last Gasps", and higher harmonics data. The meters also serve as gateways for two-way communications between the utility and other authorized parties with the customers. They also can be used for transmitting prices and other triggering signals for enabling DR, control of customer-side DERs, ES, and Plug-in Electric Vehicles (PEVs). The meters can be used by the customers for communication to the utility and other parties of their choices regarding participation in DR, DER, ES, and PEV controls. While the most commonly used information, like revenue data and interval measurements, can be retrieved from all AMI meters in greater time intervals, e.g., one a day, other selected data can be retrieved more often from a limited number of bellwether meters.
AMI Data Management System	AMI Data Management System communicates with Smart Meters, collects, stores, and processes measurements from the Smart Meters. It is interfaced with other data management

Actor/System/Information/Contract	*Preconditions or Assumptions*
	system, such as GIS, DER, DR, and PEV and with the DMS system, through which it provides and receives information in accordance with the designs of the relevant object models and DMS applications.
CIS database	The Customer Information System (CIS) contains energy consumption and load data for each customer separate, even for the ones, which are included in consolidated accounts, based on measurement interval established for the Smart Meters and also aggregated for established billing periods. CIS interfaces with GIS and other data management systems according to the designs of the object models used in DMS and the designs of the DMS applications.
DER	Large DER are able to generate real and reactive power, absorb reactive power, and are equipped with gateways able to communicate with SCADA and with controllers able to monitor and control the operations of DER based on either local, or remote inputs, and may contain a portion or entirely the object model of DER. DER embedded in the customer domain are interfaced with other parties through a Smart Meter or another customer-oriented gateway, are able to respond to utility requests, to price signals and other triggers, some DER are also able to generate and absorb reactive power, including some at times, when the DER does not generate real power. The DER object model includes the multi-dimensional capability curves (tables).
DER data management system	Controlling DER and ES charging/discharging based on DMS requests/commands or based on contracts between the DER owner and the aggregator; processing and storing data on contracts, relevant historic information, creating adaptable models of DER, collecting, processing, and storing power quality and reliability characteristics, etc. according to the designs of the object models and DMS applications
DR data management system	Controlling DR based on DMS requests/commands or based on contracts between the customer and the aggregator, processing and storing data on load management programs, contracts, relevant historic information, creating adaptable models, collecting, processing, and storing customer-specific data according to the designs of the object models and DMS applications.
PEV data management system	Encouraging or discouraging charging PEV through relevant pricing or other incentives/disincentives obtained from DMS, processing and storing data on PEV programs,

Actor/System/Information/Contract	*Preconditions or Assumptions*
	contracts, relevant historic information, creating adaptable models, collecting, processing, and storing customer-specific data according to the designs of the object models and DMS applications.
SCADA/EMS	The Transmission Energy Management System (EMS) system contains the transmission power system model, and can provide the transmission connectivity, relevant facility e, and operational information on the transmission system in the vicinity of the distribution power system. EMS accepts information from the TBLM for the use in the EMS applications and transmits requests/commands from EMS applications to the TBLM to be executed by the DMS in accordance with the design of the DMS applications.
Customer Energy Management System	Customer Energy Management System can receive pricing and other signals for managing customer devices, including appliances, DER, electric storage, and PEVs. It provides DMS and/or relevant Data Management Systems with it entire or partial object model, including near-real time states.
Energy Services Interface (ESI)	Provides cyber security and, often, coordination functions that enable secure interactions between relevant Home Area Network Devices and the Utility. Permits applications such as remote load control, monitoring and control of distributed generation, in-home display of customer usage, reading of non-energy meters, and integration with building management systems. Provides auditing/logging functions that record transactions to and from Home Area Networking Devices. Can also act as a gateway and can be a part of the Customer Energy Management System. .
DMS conversion and validation function (C&V)	The C&V function uses standard interface between AM/FM/GIS database and converts and validates information about incremental changes implemented in the field.
DMS: Distribution Operation Modeling and Analysis (DOMA)	Distribution SCADA with several IEDs along distribution feeders, reporting statuses of remotely controlled switches and analogs including Amps, kW, kvar, and kV. Operator's ability for updating the SCADA database with statuses of switches not monitored remotely (outage detection by AMI can be used also). Substation SCADA with analogs and statuses from CBs exists. EMS is interfaced with DMS. DMS database is updated with the latest AM/FM/GIS/CIS/AMI data and operators input. The options for DOMA performance are selected. DOMA includes adaptable load models, including Demand Response with all

Actor/System/Information/Contract	*Preconditions or Assumptions*
	dependencies on external factors, and adaptable DER and ES models. These models are updated by the corresponding data management systems. The DMS database is updated by the real-time state of communication with IEDs and the availability of switch control. DOMA is able to run automatically within given ranges of operational and price parameters either specified for the TBLM or determined by the set of IVVWOst runs within these ranges.
DMS: Distribution Contingency Analysis (DCA)	The conventional N-m DCA is upgraded to integrate the DER and DR and to analyze the behavior of the Active Distribution Network in cases of disturbances in the bulk power system. Voltage angles are provided by EMS State estimation and are taken into account by the DCA. Voltage, Var, and Watt Optimization in the study mode is integrated with DCA for adjusting voltage and var after reconfiguration. The output of the DCA is available for the use by the TBLM developer.
DMS: Multi-level Feeder Reconfiguration in study mode (MFRst)	This application is available in case there is a request from the EMS or OMS to move load from buses with high LMP to busses with lower LMP. MFRst is able to include DER and micro-grids in the MFRst solutions. Voltage angles are provided by EMS State estimation and are taken into account by the MFRst. Voltage, Var, and Watt Optimization in the study mode is integrated with MFRst for adjusting voltage and var after reconfiguration. The output of the MFRst is available for the use by the TBLM developer to provide the ranges of availability.
DMS: Voltage, Var, and Watt Optimization in study mode (VVWOst)	IVVO is able to run automatically within given ranges of operational and price parameters either specified for the TBLM requirements or determined by the set of DCAst and MFRst runs within these ranges.
DMS: Coordination of emergency actions in study mode (CEAst)	A. This application interfaces with the DCA and determines the sequence of emergency actions for optimum mitigation of the contingency.
DMS: Load Management systems in study mode(LMSst)	LMSst is able to perform "what if" analyses based on predefined ranges of possible external signals, which may come either from the TBLM setup, or from DMS applications (e.g., reliability prices from DCAst or Demand response requests from IVVWOst). It is able to simulate the response to these signals by the DR, DER, PEV and ES and submit the results to

Actor/System/Information/Contract	*Preconditions or Assumptions*
	DOMA and IVVWOst. The LMS may include the load-modeling processor.
DMS: Under-Frequency Load Shedding Analyzer (UFLSA)	UFLSA is able to simulate the behavior of the UFLS and DER under-frequency protection schemes under low frequency conditions due to bulk power emergencies. It is also coordinated with the analyses of the behavior of DR and other load shedding/management means under the same conditions. It determines and takes into account the overlapping of loads under different load shedding/management actions. The results of the analyses are submitted to the DCAst and other relevant applications. The parameters of the UFLS within the Micro-grids are known. UFLS can be coordinated with UVLS, SLS, DR, DER and IVVWO operations based on the Coordination of Emergency Actions application.
DMS: Under-Voltage Load Shedding Analyzer (UVLSA)	UVLSA is able to simulate the behavior of the UVLS and DER under-voltage protection schemes under low voltage conditions due to bulk power emergencies. It is also coordinated with the analyses of the behavior of DR and other load shedding/management means under the same conditions. It determines and takes into account the overlapping of loads under different load shedding/management actions. The results of the analyses are submitted to the DCAst and other relevant applications. The parameters of the UVLS within the Micro-grids are known. UVLS can be coordinated with UFLS, SLS, DR, DER and IVVWO operations based on the Coordination of Emergency Actions application
DMS: Special Load Shedding Analyzer (SLSA)	SLSA is able to simulate the behavior of the SLS under the defined special conditions (e.g., opening of a particular switching device(s) in the transmission system). It is also coordinated with the analyses of the behavior of DER, DR and other load shedding/management means under the same conditions. It determines and takes into account the overlapping of loads under different load shedding/management actions. The results of the analyses are submitted to the DCAst and other relevant applications. SLS can be coordinated with UFLS, UVLS, DR, DER and IVVWO operations based on the Coordination of Emergency Actions application.
Communication means	Interoperable communication means between the major actors exists

Steps

Describe the normal sequence of events, focusing on steps that identify new types of information or new information exchanges or new interface issues to address. Should the sequence require detailed steps that are also used by other functions, consider creating a new "sub" function, then referring to that "subroutine" in this function. Remember that the focus should be less on the algorithms of the applications and more on the interactions and information flows between "entities", e.g. people, systems, applications, data bases, etc. There should be a direct link between the narrative and these steps.

The numbering of the sequence steps conveys the order and concurrency and iteration of the steps occur. Using a Dewey Decimal scheme, each level of nested procedure call is separated by a dot '.'. Within a level, the sequence number comprises an optional letter and an integer number. The letter specifies a concurrent sequence within the next higher level; all letter sequences are concurrent with other letter sequences. The number specifies the sequencing of messages in a given letter sequence. The absence of a letter is treated as a default 'main sequence' in parallel with the lettered sequences.

Sequence 1:

1.1 - Do step 1

1.2A.1 - In parallel to activity 2 B do step 1

1.2A.2 - In parallel to activity 2 B do step 2

1.2B.1 - In parallel to activity 2 A do step 1

1.2B.2 - In parallel to activity 2 A do step 2

1.3 - Do step 3

1.3.1 - nested step 3.1

1.3.2 - nested step 3.2

Sequence 2:

2.1 - Do step 1

2.2 – Do step 2

The development of the Transmission Bus Load model is a multi-branched application that collects primary data from different sources to be used in a number of branched-off scenarios.

The step-by-step actions of this use case are described below first for the collection of the common primary information and then for following scenarios of supporting the TBLM in near-real time.

1. Develop aggregated DER capability curves for TBLM

2. Develop aggregated model of dispatchable load for TBLM

3. Develop aggregated real and reactive load-to-voltage dependencies

4. Develop aggregated real and reactive load-to-frequency dependencies
5. Develop aggregated real and reactive load dependencies on Demand response control signals
6. Develop aggregated real and reactive load dependencies on dynamic prices,
7. Adapt aggregated real and reactive load dependencies to weather conditions, etc.
8. Develop aggregated real and reactive load dependencies on ambient conditions.
9. Develop models of overlaps of different load management functions, which use the same load under different conditions.
10. Assess the degree of uncertainty of TBLM component models
11. Develop Virtual Power Plant technical models
12. Develop Virtual Power Plant economic models
13. Develop aggregated model of DER based on ownership of DER, ways of controlling (jurisdiction, related to regulatory issues)

The step-by-step sequence of events described in Table 4 is for the collection of common data.

Table 4. Step-by-step action for collecting common data to be used for the development of the TBLM

#	Event [1]	Primary Actor [2]	Name of Process/Activity [3]	Description of Process/Activity [4]	Information Producer [5]	Information Receiver [6]	Name of Info Exchanged [7]	Additional Notes [8]

#	*Triggering event.: Identify the name of the event.*[1]	*What other actors are primarily responsible for the Process/Activity. Actors are defined in section2.*	*Label that would appear in a process diagram. Use action verbs when naming activity.*	*Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.*	*What other actors are primarily responsible for Producing the information. Actors are defined in section2.*	*What other actors are primarily responsible for Receiving the information Actors are defined in section2. (Note – May leave blank if same as Primary Actor)*	*Name of the information object. Information objects are defined in section 3*	*Elaborate architectural issues using attached spreadsheet. Use this column to elaborate details that aren't captured in the spreadsheet.*
1.1	DMS scheduler polls Distribution SCADA database for data relevant to DMS advanced applications	DMS scheduler	Polling near real-time data from Distribution SCADA (DSCADA)	DMS retrieves data pertinent to the scope of DMS for the subject area	DSCADA	DMS scheduler	DSCADA snapshot	Data include analogs and statuses collected by DSCADA from remotely monitored devices in distribution
1.2	DMS scheduler polls EMS/SCADA database for data relevant to DMS	DMS scheduler	Polling near real-time data from EMS/SCADA	DMS retrieves data pertinent to the scope of DMS for the subject area	EMS/SCADA	DMS scheduler	EMS/SCADA snapshot	Data include analog and statuses collected by EMS/SCADA from substations and data from EMS and MOS applications
1.3	DMS scheduler polls External system databases for data relevant to DMS	DMS scheduler	Polling near real-time databases from external data bases	DMS scheduler retrieves data pertinent to the scope of DMS for the subject area	External systems	DMS scheduler	External data snapshot and short-term forecast	Data include current and forecast weather data by relevant areas

[1] Note – A triggering event is not necessary if the completion of the prior step leads to the transition of the following step.

1.4	AMI Data Management System received new data from the selected bellwether meters	AMI Data Management System	Updates of data obtained from bellwether meters	Analyzing the data from localized areas to derive the characterization of the local weather conditions, like impact of the temperature, level of cloudiness and its changeability, wind direction and velocity, etc.	Bellwether meters, CEMS, other customer-site sensors	AMI Data Management System	Supplemental data from bellwether meters	It is unlikely that the smart meters will collect all environmental data. However, by analyzing the historic patterns of load and DER performance under different weather conditions from the bellwether meters of a particular area, the essential components of the load and DER models can be categorized for the entire local area.

1.5	DER Data Management System received new data from the selected DER/Micro-grid controllers	DER Data Managem ent System	Checking for significant changes of data obtained from selected DER/micro-grid controllers	Analyzing the data from localized areas to derive the characterization of the local weather conditions, like impact of the temperature, level of cloudiness and its changeability, wind direction and velocity, etc. Also updating the modes and settings of DER operations.	Selected DER controllers/sen sors, CEMS, other customer-site sensors	DER Data Management System	Supplement al data from selected DER-sites.	By analyzing the historic patterns of DER/micro-grid performance under different weather conditions of a particular area, the essential components of the DER models can be categorized for the entire local area. For instance, if the PV DER performance recorded under clear sky at a given time is the reference conditions, and the data from the bellwether meters collected during a representative time interval show that the average DER generation is, say, 50% of the reference load with a standard deviation of 5%, it is likely a light overcast condition and can be presented as a particular category of DER performance. If the standard deviation were 20%, it would likely be due to fast-moving clouds, and would be presented by another category. In addition to weather conditions, the modes of DER operations and their settings may change based on utility request and/or on aggregators request. This information can be retrieved from the DER controllers or may be in the DER management system submitted by the DMS applications or by the aggregators.

1.6	Load Management System received new data for DR and/or other load management means from different sources related to load management	Load Management System	Checking for significant changes of data obtained from relevant sources	Analyzing the load management triggers to derive clusters of loads with similar triggers.	EMS, Aggregators, DMS	Load Management System	Updates of load management triggers	To reduce the dimension of DMS database, it is desirable to divide the load models into clusters with similar attributes. For instance, the clusters can be based on the types of the Demand Response program and on the presence of a particular type of a DER embedded in the load.
1.4.1	AMI Data Management System derived a new pattern of load conditions	AMI Data Management System	Update of local external conditions for load models	AMI Data Management System provides DMS database with the updated external factors that may impact the load models used by DMS applications	AMI Data Management System	DMS database	Update of local external conditions	The adaptive load models contain load dependencies on different factors, including weather conditions
1.5.1	DER Data Management System derived a new pattern of DER conditions and modes of operations	DER Data Management System	Update of local external conditions for DER models	DER Data Management System provides DMS database with the updated external factors that may impact the DER models used by DMS applications	DER Data Management System	DMS database	Update of local external conditions and local modes of operations	The adaptive DER models contain DER-performance dependencies on different factors, including weather conditions and local volt/var conditions
1.6.1	Load Management System determined significant changes of load management triggers	Load Management System	Update of triggers for load management	Load Management System provides DOMA database with the updated triggers that may impact the load and DER models used by DMS applications	Load Management System	DOMA database	Update of triggers for DR and other load management means	Load management triggers impact the load patterns according to the load management (Demand Response) programs in combination with other external factors

2.	Last snapshots received by DMS scheduler	DMS scheduler	Consolidating snapshots	DMS scheduler consolidates and synchronizes the received snapshots and analyzes the snapshots for pre-defined events and for periodic times of DOMA execution and places incremental changes into DMS database	DMS scheduler	DMS database	Update of DMS database	
3.1	There are changes of statuses and significant analog changes in distribution and/or there are changes of external data (including EMS/SCADA) in the consolidated snapshot, or it is the time for a periodic run of an application. No fault indicators either from field IEDs, or from AMI.	DMS scheduler	Launching DOMA	DMS scheduler sends a command to start DOMA due to pre-defined changes in the consolidated snapshot	DMS scheduler	DOMA application	Commands for starting DOMA	The significance of events should be determined based on the specifics of the local distribution network and on the sensitivity of the transmission operations to the event.

3.2	There are significant changes of adaptive load or DER models, or there are significant changes of local external factors posted in the DMS database by either AMI or DER Data Management Systems, or by Load Management systems,.	DMS database	Launching DOMA	DMS database sends a command to start DOMA due to pre-defined changes in the database	DMS database	DOMA application	Commands for starting DOMA	The significance of changes should be determined based on the specifics of the local distribution network and on the sensitivity of the transmission operations to the change.
3.3	There are no changes of statuses in distribution and there are no changes of external data in the consolidated snapshot, and there are no changes in the DMS database. No fault indicators either from field IEDs, or from AMI.	DMS scheduler	Back to 1.x					

4.1	DOMA received the command to start	DOMA	Check for load model updates (if the latest models are not previously submitted by the Load Model Processor)	DOMA checks the Load model processor for not acknowledged changes of the adaptive load models. If yes, DOMA incrementally updates its load models and acknowledges the updates.	Load model processor	DOMA	Updated load models	The load models are developed by the Load Model Processor based on the historic data provided by the AMI Data Management System. This historic data may change the previously developed load models, including the load dependencies on external factors. The new models can be pushed out to the DMS database, or can be pulled by DOMA from the Load Model Processor.
4.2	DOMA received the command to start	DOMA	Check for DER model updates (if the latest models are not previously submitted by the DER Model Processor)	DOMA checks the DER Model Processor for not acknowledged changes of the adaptive load models. If yes, DOMA incrementally updates its load models and acknowledges the updates.	DER model processor	DOMA	Updated DER models	The DER models are developed by the DER Model Processor based on the historic data provided by the DER Data Management System. This historic data may change the previously developed DER models, including the DER performance dependencies on external factors. The new models can be pushed out to the DMS database, or can be pulled by DOMA from the DER Model Processor.
4.3	DOMA received the command to start	DOMA	Check for load management trigger updates	DOMA checks the Load Management System for not acknowledged changes of the load management triggers. If yes, DOMA incrementally updates its load models and acknowledges the updates	Load Management System	DOMA	Updated Load Managemen t triggers	

5	DOMA received all updated input data	DOMA	DOMA adjusts the component models	DOMA adjusts the topology and adaptive models based on the latest external factors in the DMS database. The following models are updated: • Transmission/Sub-Transmission System Immediately Adjacent to Distribution Circuits • Distribution Circuit Connectivity • Distribution Nodal Loads • Distributed Energy Resources (DER) and Micro-grids • Distribution Circuit Facilities • Demand Response models	DMS database	DOMA	Update of DOMA input data	
5	DOMA finished updates of the models and executes	DOMA	DOMA executes	DOMA updates the model of the Distribution Power flow and the analysis of operations and informs the TBLM Developer that the reference distribution operation model is updated and ready for use.	DOMA	TBLM developer	Initiating the TBLM Developer	

6	TBLM Developer is initiated	TBLM Developer	TBLM Developer started	The TBLM Developer starts actions according to the needs of the predefined scenarios for the development of the components of the TBLM	TBLM Developer	Series of Study modes executions of DOMA and IVVWO	Development of the TBLM	See the use cases for the individual scenarios.

Scenarios 1 &2. Develop the aggregated DER capability curves and the aggregated model of dispatchable load for TBLM

The step-by-step sequence of events described in Table 5 is for the first and the second scenarios:

1. Develop aggregated DER capability curves for TBLM
2. Develop aggregated model of dispatchable load for TBLM

The narrative for these scenarios is presented below:

Objectives.

- Provide near-real-time aggregated capability curves of DER in the TBLM for EMS applications
- Provide near-real-time aggregated real and reactive dispatchable load in distribution in the TBLM for EMS applications
  - Based on DER only
  - Based on DER and DR (sub-scenario)

Background Information.

It is assumed here that the capability of an inverter-based DER is limited by the rated AC current. It means that the available kvars of the DER are dependent on the kW and on the voltage at the DER terminals (illustrated in *Figure 9*).

The voltages at different nodes along the distribution circuits are different (*Figure 10*). The voltages depend on the overall operating conditions of the circuits and on the operations of the DER itself. Therefore, the available kvars from DERs located at different nodes are different even if the DERs are identical (illustrated in *Figure 11*).

Hence, the DER capabilities aggregated at the transmission bus are different under different bus voltages and should be presented as dependences on the bus voltage (illustrated in *Figure 12*).

The dispatchable kvars aggregated at the transmission bus (Scenario 2) depends on the initial loading of the DERs, on the DER capability curve, and on the mode of operations of the DER (illustrated in *Figure 13*).

The capability curves and the dependences of the dispatchable load can be presented either in the form of equations, or as tables (illustrated in Figure 14).

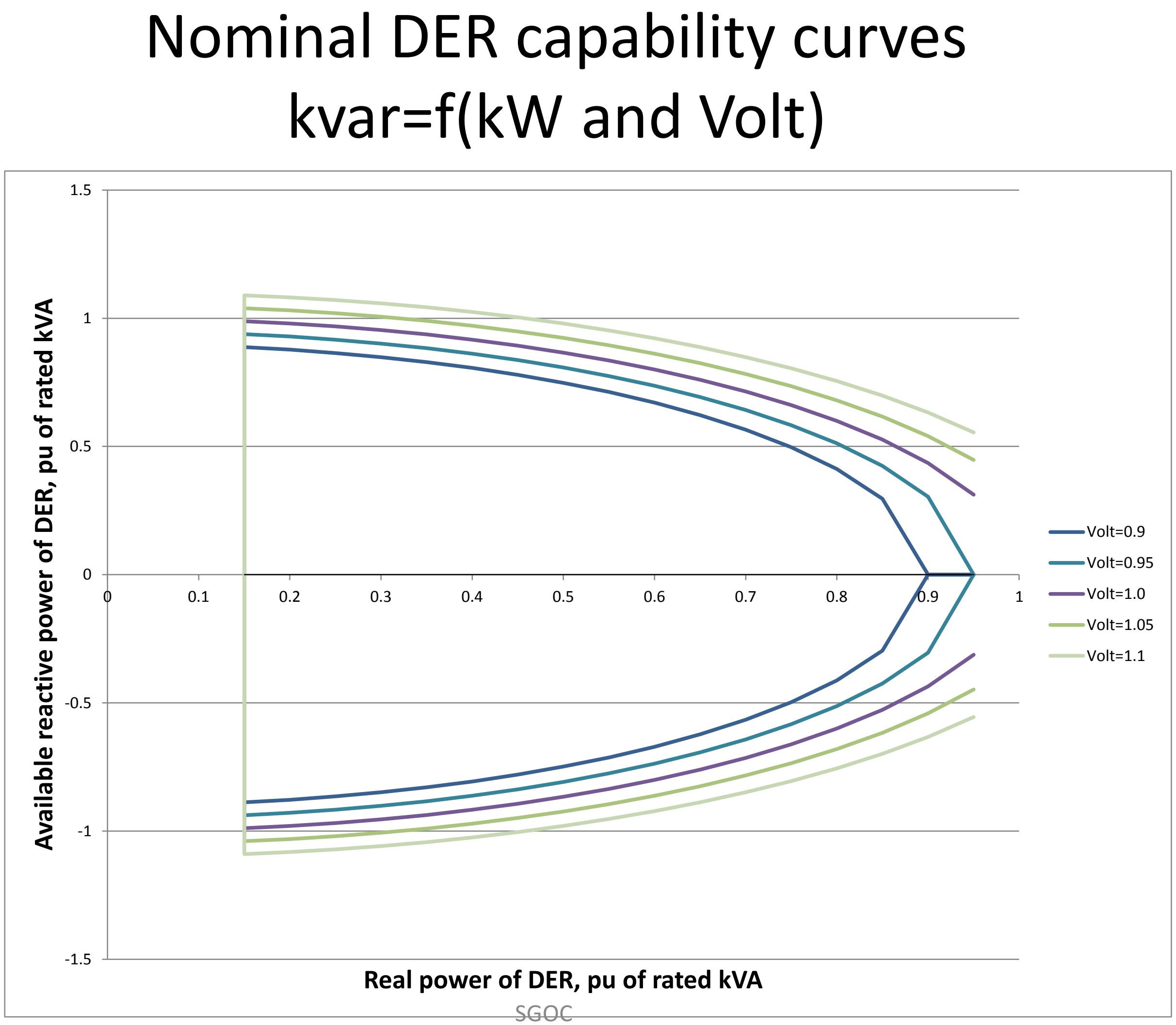


Figure 9. DER capability curve

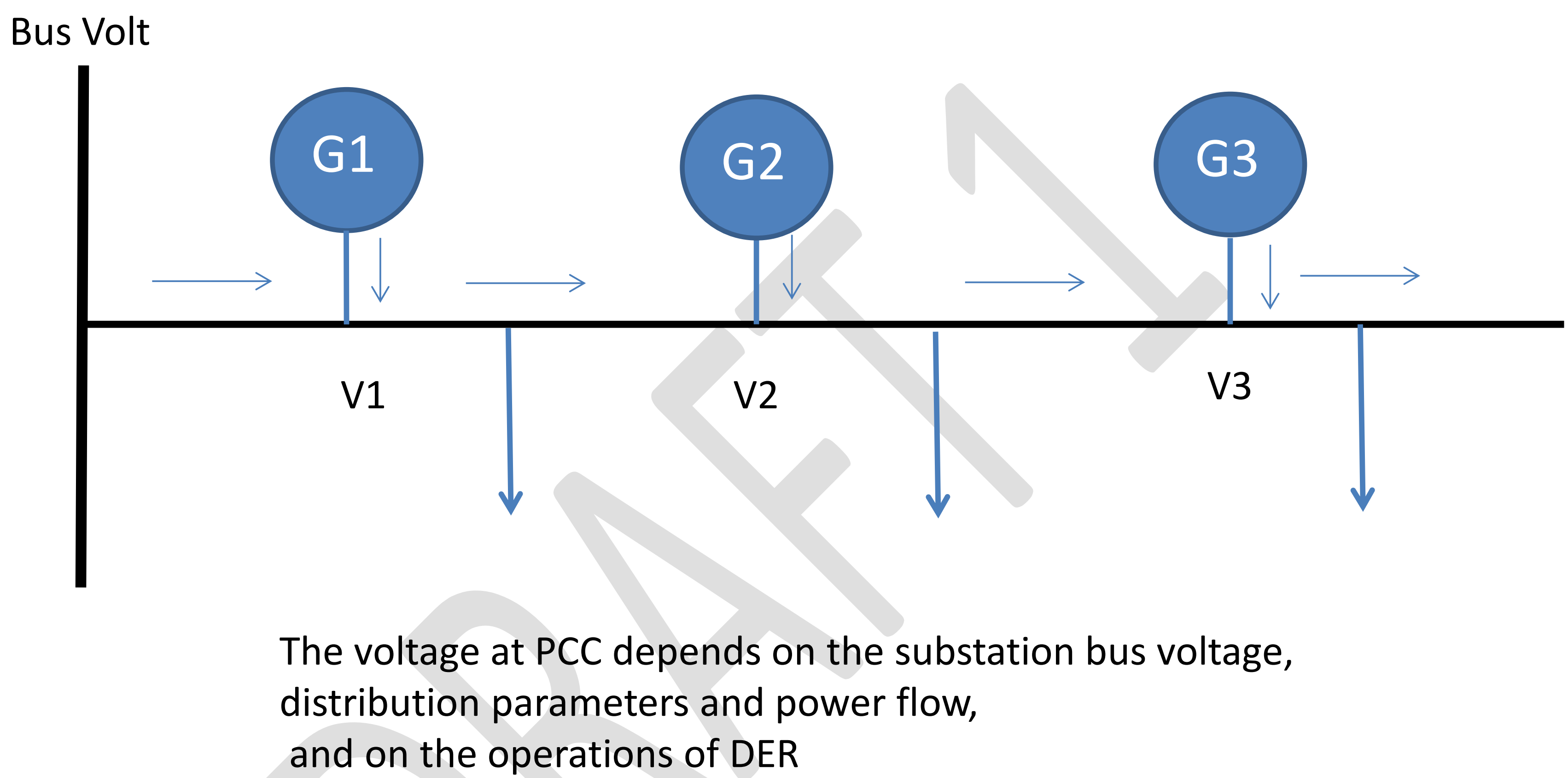


Figure 10. The actual voltages are different at different PCCs

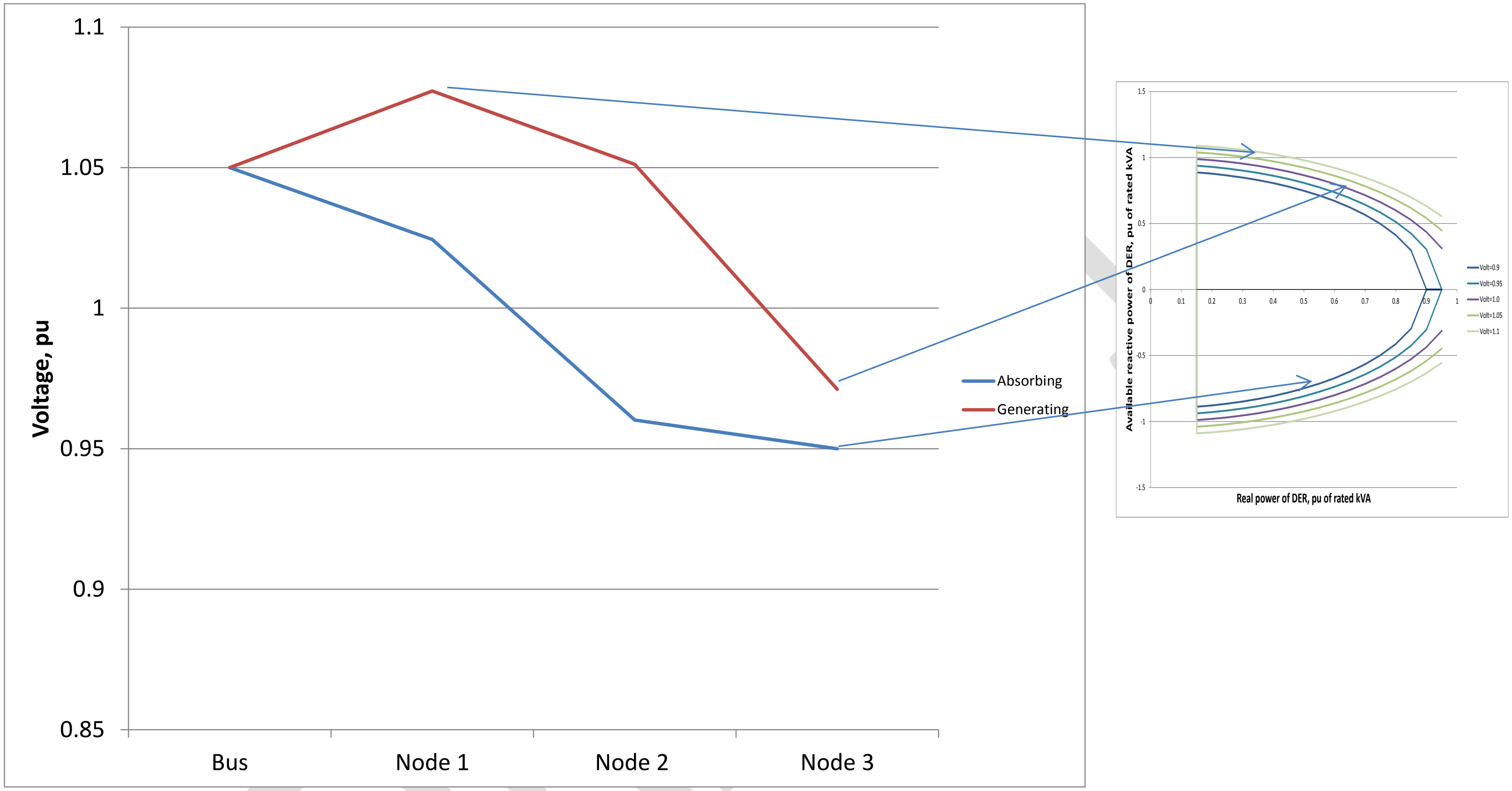


Figure 11. Voltage profile along feeder with DER in different modes.

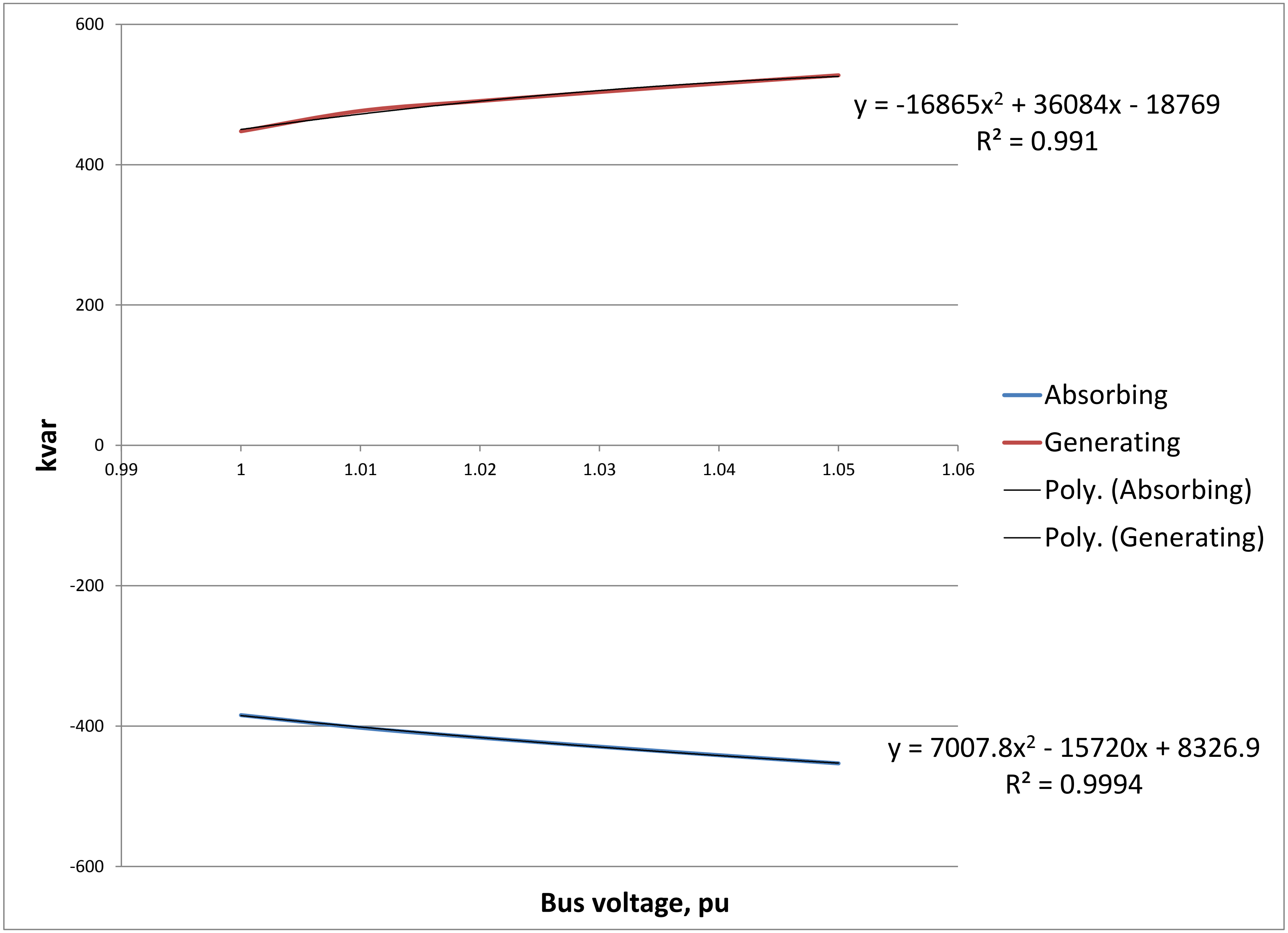


Figure 12. Near-real-time aggregated capability curves in the TBLM

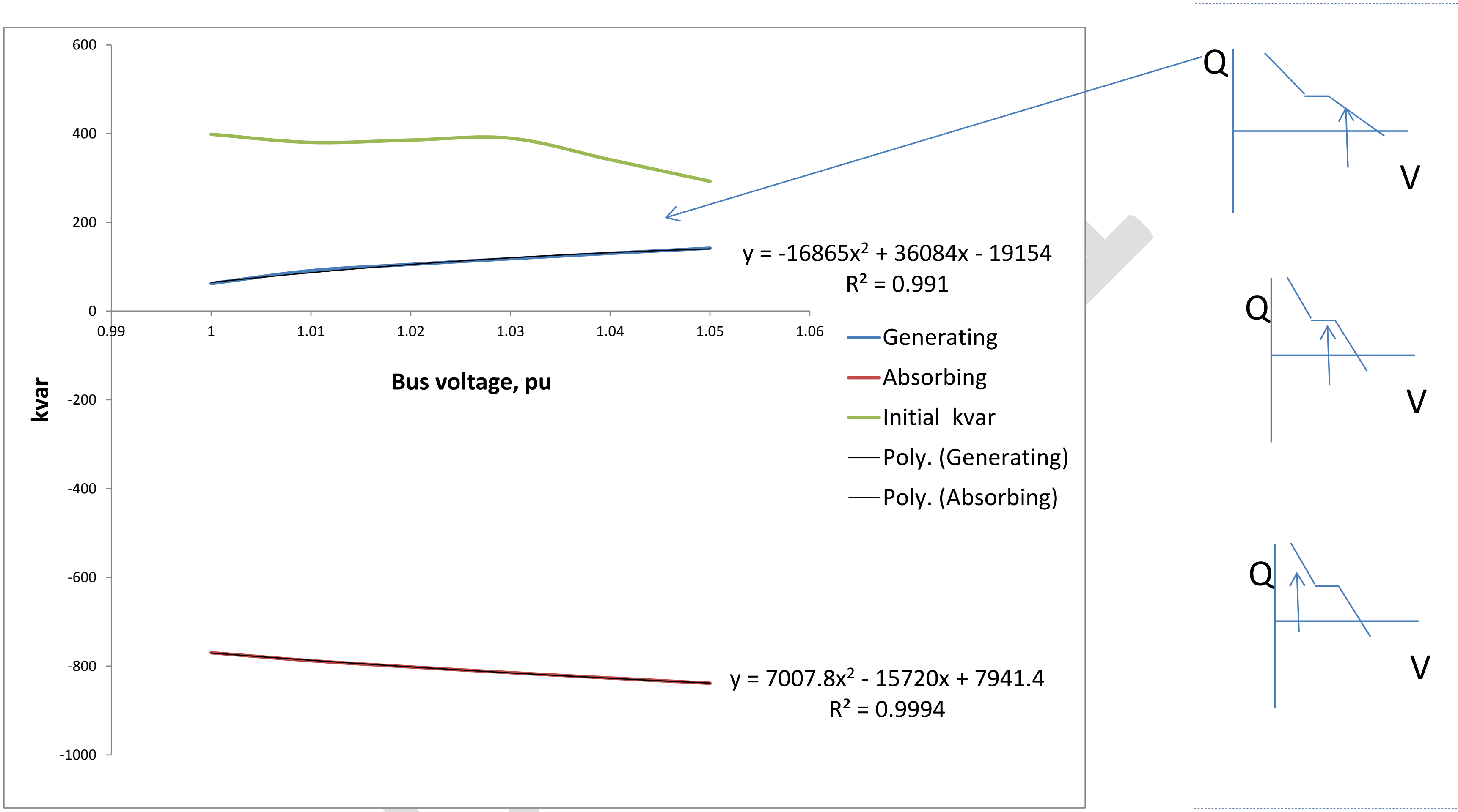


Figure 13. Dispatchable aggregated reactive load in the TBLM

- Equations: kvar = $-16865V^2 + 36084V - 18769$, $R^2 = 0.991$
  - V= bus voltage
- Tables
  - Capability curves:

Bus Voltage, pu	Absorbing	Generating
1	-384.27	447.57
1.01	-402.218	476.55
1.02	-416.314	490.64
1.03	-429.176	503.49
1.04	-441.325	515.64
1.05	-452.981	527.29

  - Dispatchable loads:

Bus Volt	kvar up	kvar down	Initial kvar
1	62	-770	398
1.01	91	-788	380
1.02	105	-802	385
1.03	118	-815	390
1.04	130	-827	341
1.05	142	-838	292

Figure 14. Formats for representation the capability curves and dispatchable load in the TBLM

Input data for development of aggregated capability curves and dispatchable loads for the TBLM.

- Actual kW and voltages at DER PCCs
  - Sources of information:

        - DSCADA
        - DER Data Management System
        - DOMA
- Voltages at DER PCCs under different bus voltages
    - Sources of information:
        - DOMA
- Nodes and settings of DER Volt/var functions
    - Sources of information:
        - DSCADA
        - DER Data Management System

Table 5. Step-by-step actions for Scenarios 1&2

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
#	*Triggering event? Identify the name of the event.*[2]	*What other actors are primarily responsible for the Process/Activity? Actors are defined in section2.*	*Label that would appear in a process diagram. Use action verbs when naming activity.*	*Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.*	*What other actors are primarily responsible for Producing the information? Actors are defined in section2.*	*What other actors are primarily responsible for Receiving the information? Actors are defined in section2.* *(Note – May leave blank if same as Primary Actor)*	*Name of the information object. Information objects are defined in section 3*	*Elaborate architectural issues using attached spreadsheet. Use this column to elaborate details that aren't captured in the spreadsheet.*	*Reference the applicable IECSA Environment containing this data exchange. Only one environment per step.*

[2] Note – A triggering event is not necessary if the completion of the prior step – leads to the transition of the following step.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
1	Periodic or by-event trigger of DOMA (used as reference operation model)	DMS Scheduler	Trigger of DOMA	Start periodic or by-event run of DOMA based on the last snapshot of input data	DMS Scheduler	DOMA application	DOMA start		
2.1	DOMA enabled	DOMA	DOMA collects data from the Load Modeling Processor	DOMA updates adaptable load models, if needed	Load Modeling Processor	DOMA applications	Updates of adaptable load models		
2.2	DOMA enabled	DOMA	DOMA collects data from the DER Data Management System	DOMA updates the adaptable DER models	DER Data Management System	DOMA applications	Updates of adaptable DER models		
2.3	DOMA enabled	DOMA	DOMA collects data from the Load Management System	DOMA updates the states of Demand Response	Load Management System	DOMA applications	Updates of the states of Demand Response		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
3	All background data is collected by DOMA	DOMA	DOMA collects data from the last snapshot provided by the DMS scheduler	DOMA updates the status and analog data from DSCADA, EMS, Weather System, and Market systems collected by the DMS scheduler	DMS scheduler	DOMA	Updates of near-real-time input data		
4	All input data is collected by DOMA	DOMA	DOMA adapts the load and DER models based on the collected data	DOMA updates the topology model based on status data, the load and DER models based on time of day, weather, and pricing data and balances the load models with DSCADA measurements by running the state estimation.	DOMA	DOMA	Adaptation and balancing the Load and DER models		
5.1	Load and DER models adapted and balanced, state estimation and power flow calculations executed	DOMA	Adaptation of the individual near-real-time DER capabilities	DOMA adapts the individual near-real-time DER capabilities based on the power flow results and current DER states	DOMA	TBLM developer	Near-real-time DER capabilities of individual and/or groups of DER		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
5.2	Load and DER models adapted and balanced, state estimation and power flow calculations executed	DOMA	Provision of IVVWO with the updated reference model	DOMA provides IVVWO with the latest near-real time state estimation/power flow results	DOMA	IVVWO	IVVO reference model		
6.1	TBLM developer received near-real time DER capabilities	TBLM developer	Consolidation of current individual DER capabilities	The individual current DER capabilities are aggregated into DER capability at the transmission bus	TBLM developer	TBLM	Aggregated current DER capability		
6.2	TBLM developer received near-real time DER capabilities	TBLM developer	Initiating the “what-if” studies by the IVVWO under a wide range of transmission bus voltages	TBLM developer initiates the IVVWO and provides it with either default range of voltages (including emergency levels), or ranges of possible voltages based on EMS contingency analyses.	TBLM developer	IVVWO	Enabling IVVWO within given voltage ranges at the transmission bus.	If there is no IVVWO, the “what-if” studies should be performed by DOMA taking into account the existing volt/var control system	

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
7	IVVWO received the initiation signal and the operational ranges from the TBLM developer	IVVWO	IVVWO runs the "want-if" studies and provides the TBLM developer with the individual or group of DER capabilities.	IVVWO runs the "what –if" studies under the current IVVWO objective within "normal" voltage ranges and with normal voltage limits at the customer terminals and runs the studies under emergency objective within the abnormal operational ranges with emergency voltage limits at the customer terminals. The results are submitted to the TBLM developer.	IVVWO	TBLM developer	Individual DER capability curves under different transmission bus voltages.	The IVVWO can be run with different normal objectives. In this case, the capability curves will also be dependent on the objective. The IVVWO can also be run under different emergency objectives, depending on the nature of the emergency. For instance, to mitigate over-voltage in transmission, the emergency objective of IVVWO may be increase in reactive and even real loads, while mitigating the under-voltage requires reduction of the loads in distribution.	
8.1	TBLM developer received the results of IVVWO "what-if" studies.	TBLM developer	Aggregating the DER capability curves	The TBLM developer aggregates the individual DER capability curves into the TBLM as a dependency on the transmission bus voltage.	TBLM developer	TBLM	Aggregated DER capability curves		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
8.2	TBLM developer received the results of IVVWO “what-if” studies.	TBLM developer	Aggregating the individual dispatchable load	The TBLM developer aggregates the individual DER and DR dispatchable loads and the available load changes due to IVVWO into the total dispatchable load at the transmission bus. The dispatchable loads are presented as dependences on the transmission bus voltage.	TBLM developer	TBLM	Aggregated dispatchable load	The information received by the TBLM developer as results of the IVVWO “what-if” studies is sufficient to derive the dependences of the dispatchable real and reactive loads on the transmission bus voltages.	

Post-conditions and Significant Results

Describe conditions that must exist at the conclusion of the Function. Identify significant items similar to that in the preconditions section.
Describe any significant results from the Function

Actor/Activity	*Post-conditions Description and Results*

Actor/Activity	*Post-conditions Description and Results*

5 Architectural Issues in Interactions

Elaborate on all architectural issues in each of the steps outlined in each of the sequences above. Reference the Step by number. Double click on the embedded excel file – record the changes and save the excel file (this updates the embedded attachment).
FUTURE USE

Scenarios 3 & 4. Develop aggregated real and reactive load-to-voltage and load-to-frequency dependencies

The narrative for these scenarios is presented below:

Scope. The load-to-voltage and the load-to-frequency dependencies should be aggregated at the demarcation buses between the transmission and distribution domains. Such buses can be either the higher voltage side busses upstream from the substation transformers between the transmission and distribution buses, or downstream from them (distribution-side bus), as illustrated in Figure 15. The load-to-voltage dependencies should cover the normal and the emergency voltage ranges, where the emergency ranges include values beyond the voltage-related settings of Remedial Actions Schemes and DER protection schemes. The load-to-frequency dependencies should cover ranges that include values beyond the settings of the frequency-related Remedial Actions Schemes and DER protection schemes.

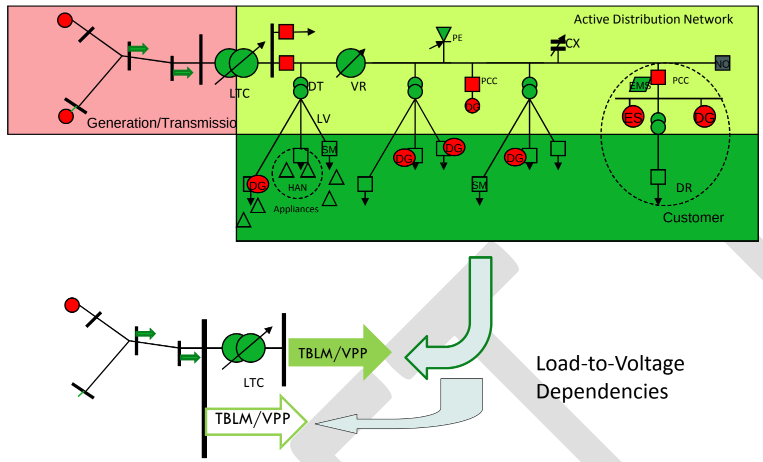


Figure 15. The demarcation buses between the transmission and distribution systems

Objectives.

- Provide near-real-time aggregated immediate real and reactive load-to-voltage dependencies in the TBLM for the dynamic EMS applications (up to seconds)
- Provide near-real-time aggregated steady-state real and reactive load-to-voltage dependencies. in the TBLM for the short-term steady-state EMS applications (up to several hours)
- Provide near-real-time aggregated real and reactive load-to-frequency dependencies in the TBLM for the dynamic security analysis EMS applications.

Background Information.

The load-to-voltage dependencies at the demarcation buses between Transmission and Active Distribution Networks are highly volatile due to the significant impacts of the high penetration of the distributed generation, including DER with volt/var controlling capabilities, multiple choices of the Volt/var control objectives and means in distribution, and other Smart-grid related factors. The aggregated at the transmission buses load-to-voltage dependencies may be significantly different at different buses at the same time and/or at different times at the same bus. The use of the same “typical” load-to-voltage dependencies for many substations and for all times may be detrimental to the security and efficiency of the power system operations (it is not just an accuracy issue).

The load-to-voltage dependencies at the transmission buses are used by a number of EMS applications, such as:

- Dynamic Security Analysis
- Steady-state Contingency Analysis with Security Constrained Dispatch
- Emergency Load Management
- Sensitivity Analysis
- Optimal Power Flow, including Volt/var Management

The aggregated load-to-voltage dependencies are a sum of multiple components, such as:

- Dependencies of nodal loads on the voltages at the load terminals, which are different in different nodes
- Dependencies of stand-alone and embedded distributed generation, which, in turn, depend on
  - the local voltage
  - capability curves
  - mode of operations
  - settings of local control
  - low/high voltage ride-through settings
- Dependencies of reactive power resources on the local voltages along the feeders
- Loss dependencies on voltages along the feeders

In addition, the steady-state load-to-voltage dependencies are impacted by the reaction of time-delayed voltage and var controllers operating autonomously and/or under a central volt/var controlling application.

All these components may change in near-real time, and so can change the aggregated at the transmission bus load-to-voltage dependency.

Figure 16 through Figure 23 illustrate different reactive load-to-voltage dependences of loads with embedded PV with inverters capable of generating/absorbing reactive power for some of the mentioned above conditions. As seen in the figures, the differences in the load models in these cases may be considerably significant, as can be their sum aggregated at the transmission bus.

As follows from the above discussion, and from the fact that the individual load dependences may significantly differ, a large amount of information should be retrieved from the multiple sources or their representatives (Data Management Systems) in the near-real time over different communications means.

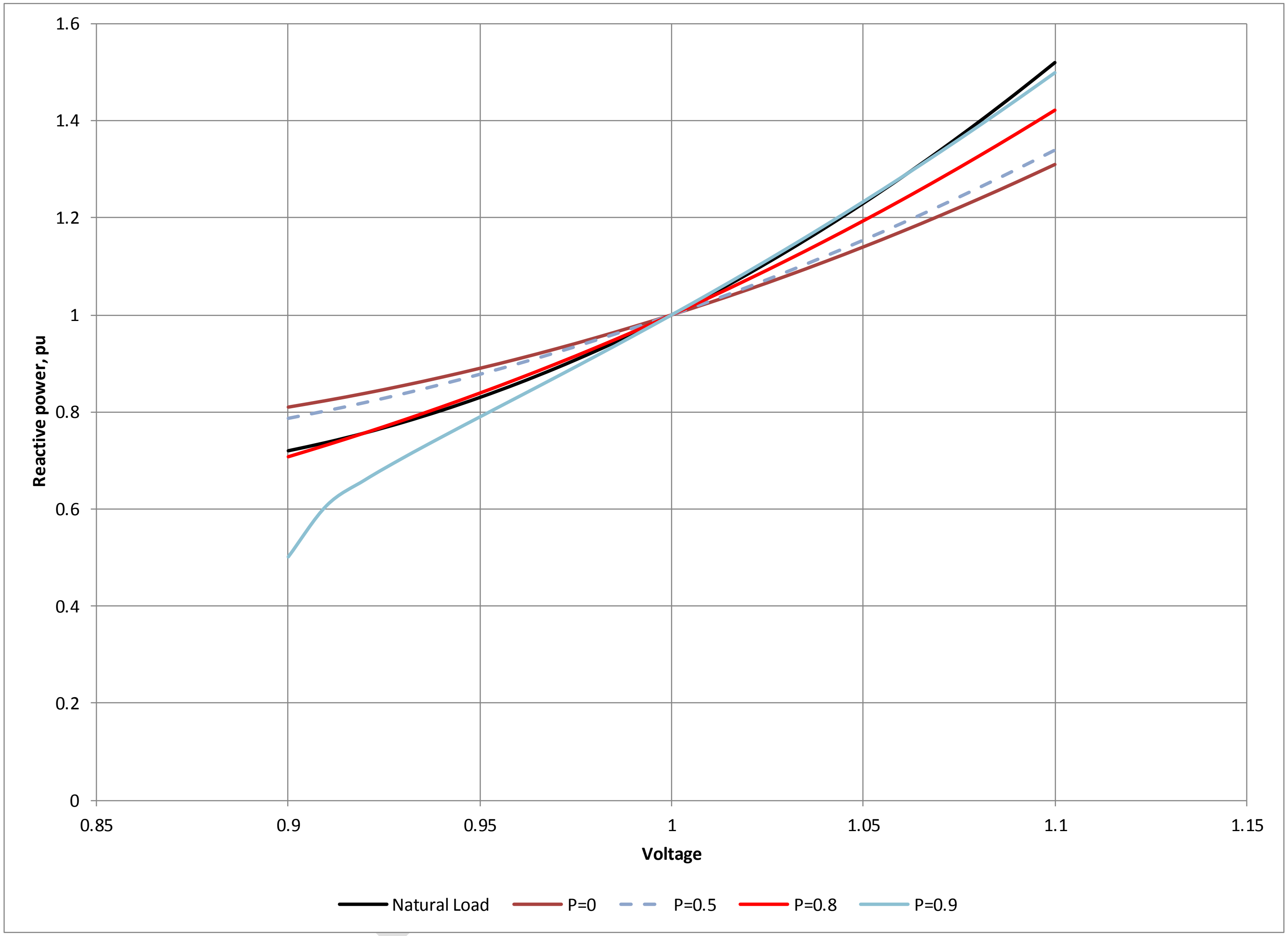


Figure 16. Reactive load-to-voltage dependency of load with embedded PV inverter in maximum inductive mode

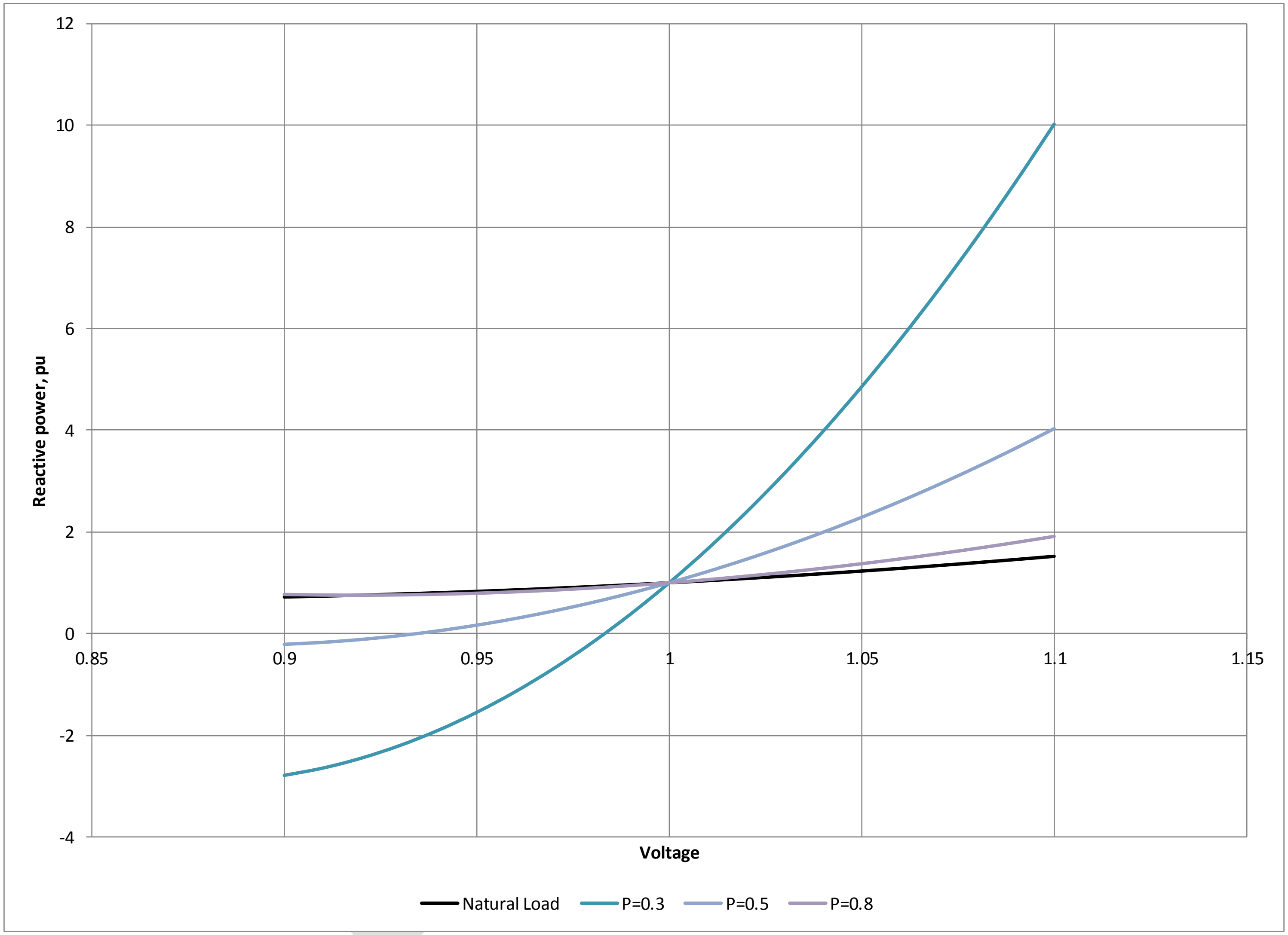


Figure 17. Reactive load-to-voltage dependency of load with embedded PV inverter in maximum capacitive mode

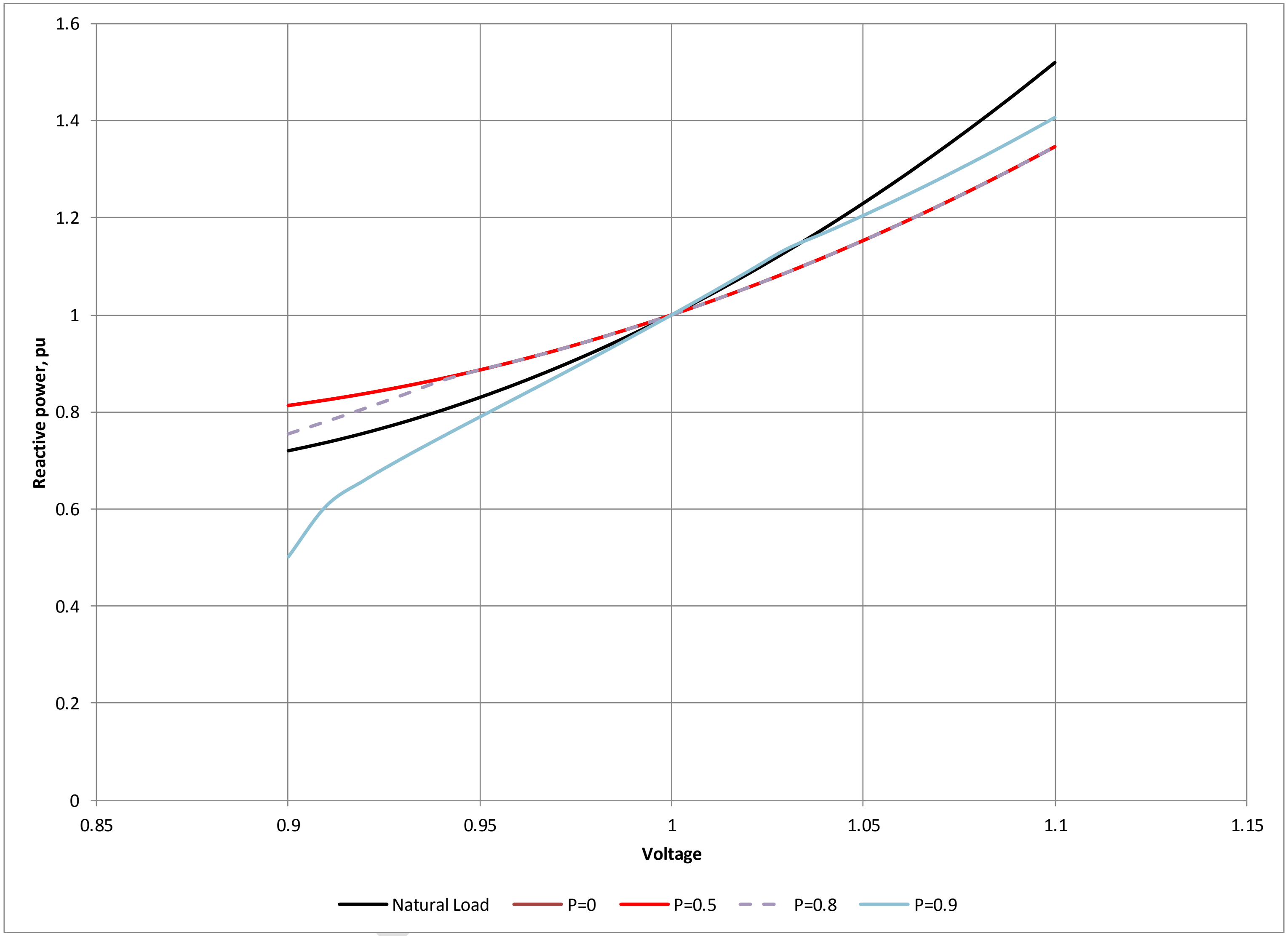


Figure 18. Reactive load-to-voltage dependency of load with embedded PV inverter in constant inductive Q mode

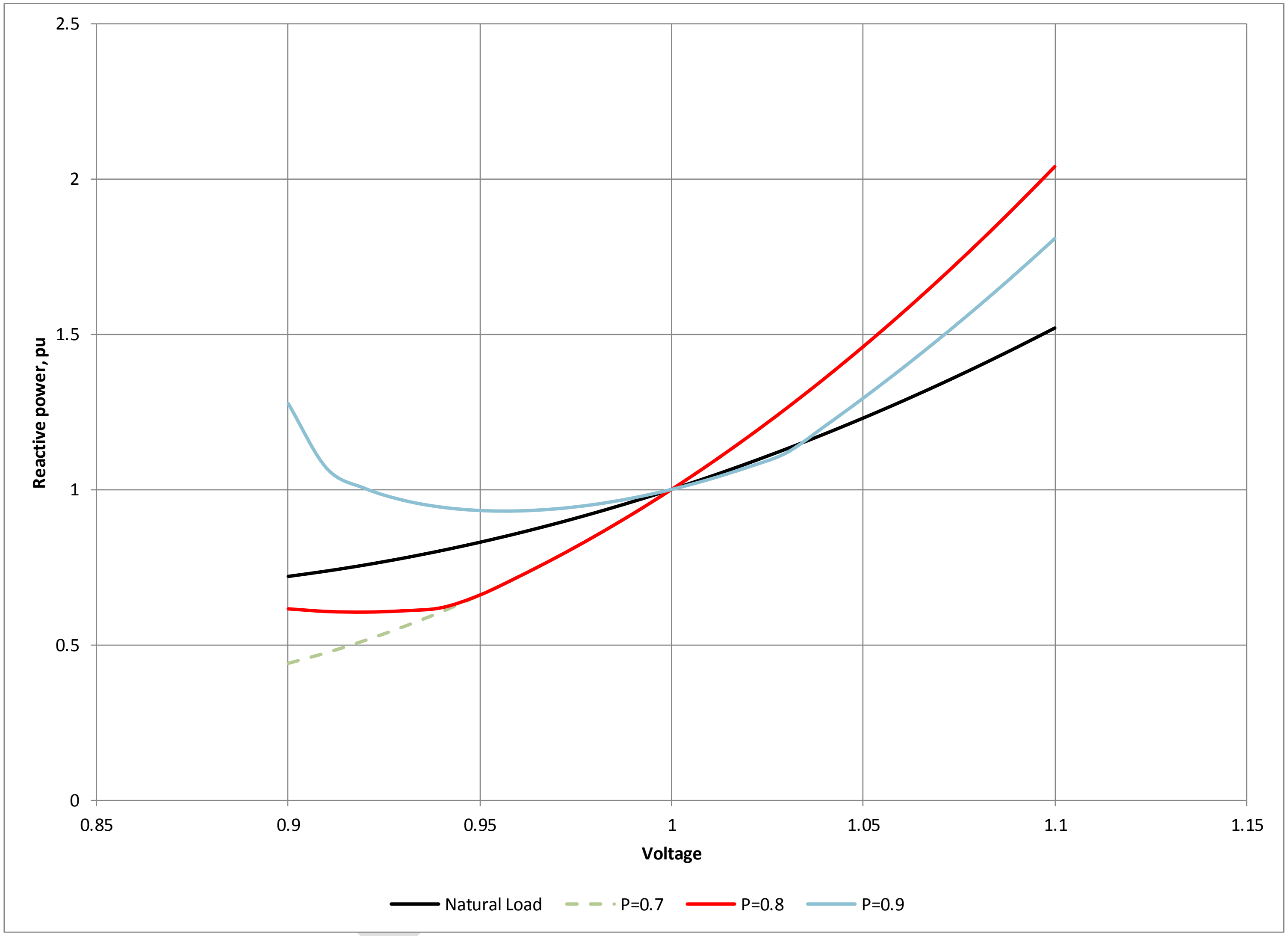
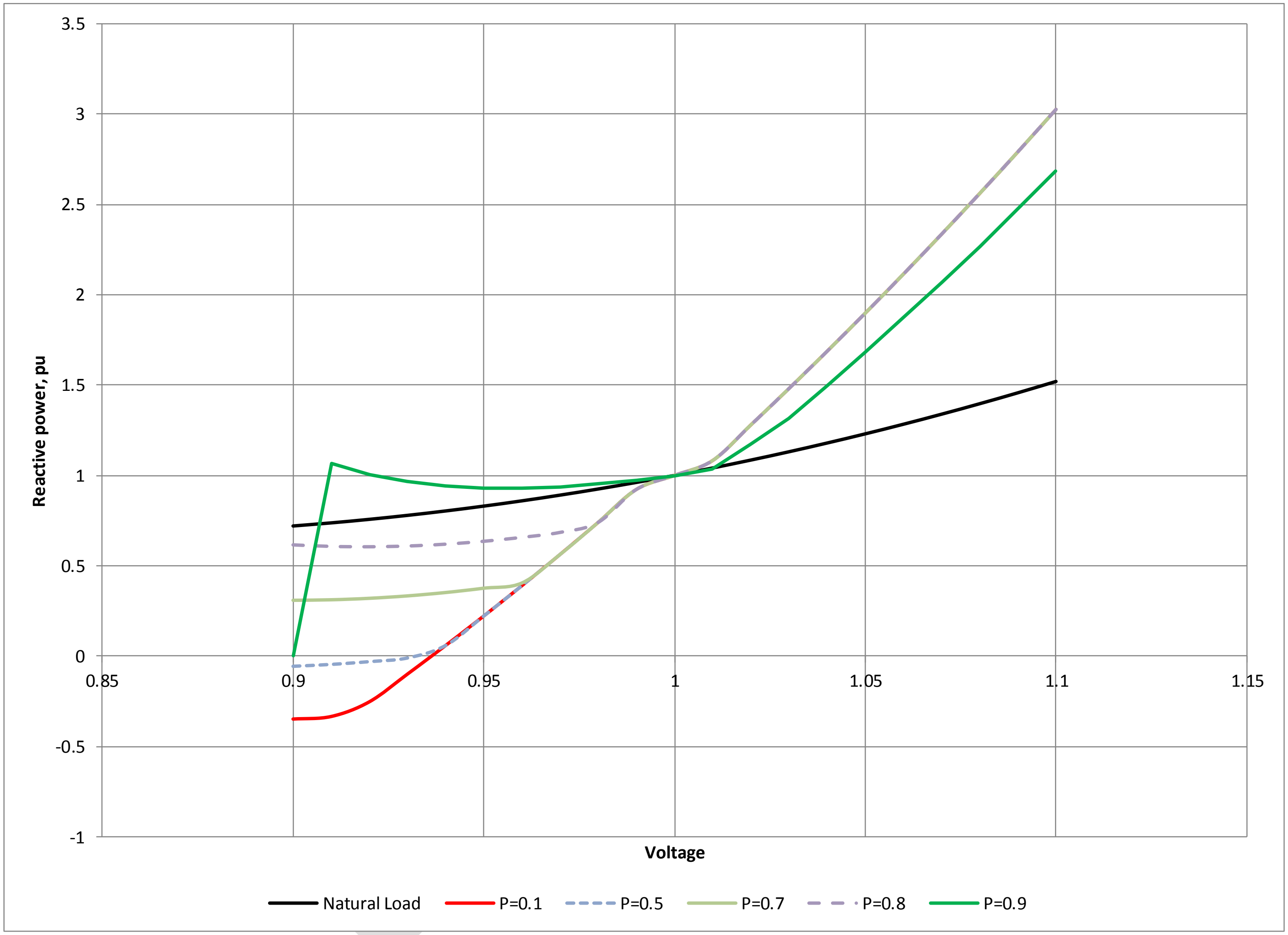


Figure 19. Reactive load-to-voltage dependency of load with embedded PV inverter in constant capacitive Q mode



1

2 **Figure 20. Reactive load-to-voltage dependency of load with embedded PV inverter in constant Q mode with voltage override**

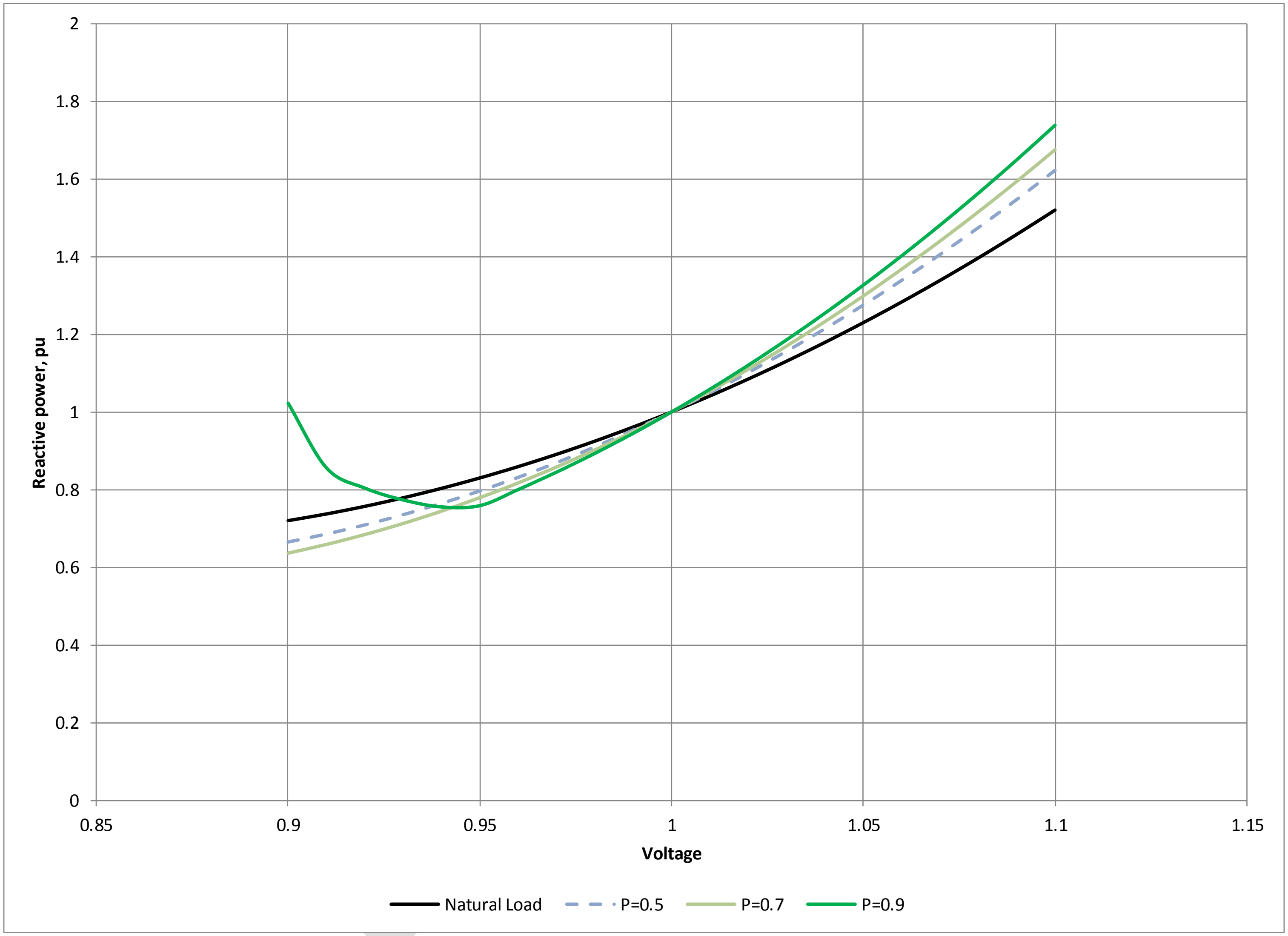


Figure 21. Reactive load-to-voltage dependency of load with embedded PV inverter in constant leading Power Factor mode

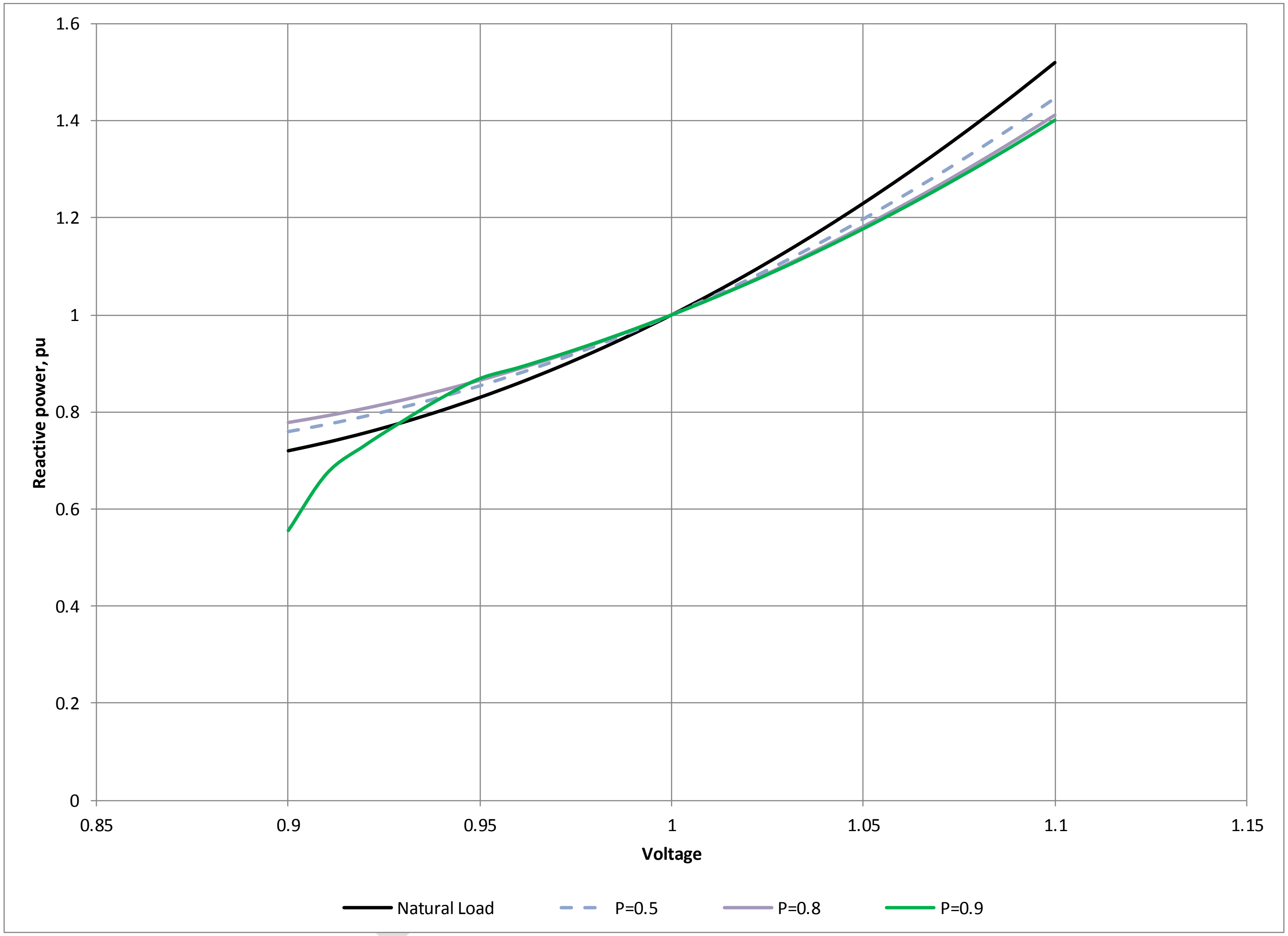


Figure 22. Reactive load-to-voltage dependency of load with embedded PV inverter in constant legging Power Factor mode

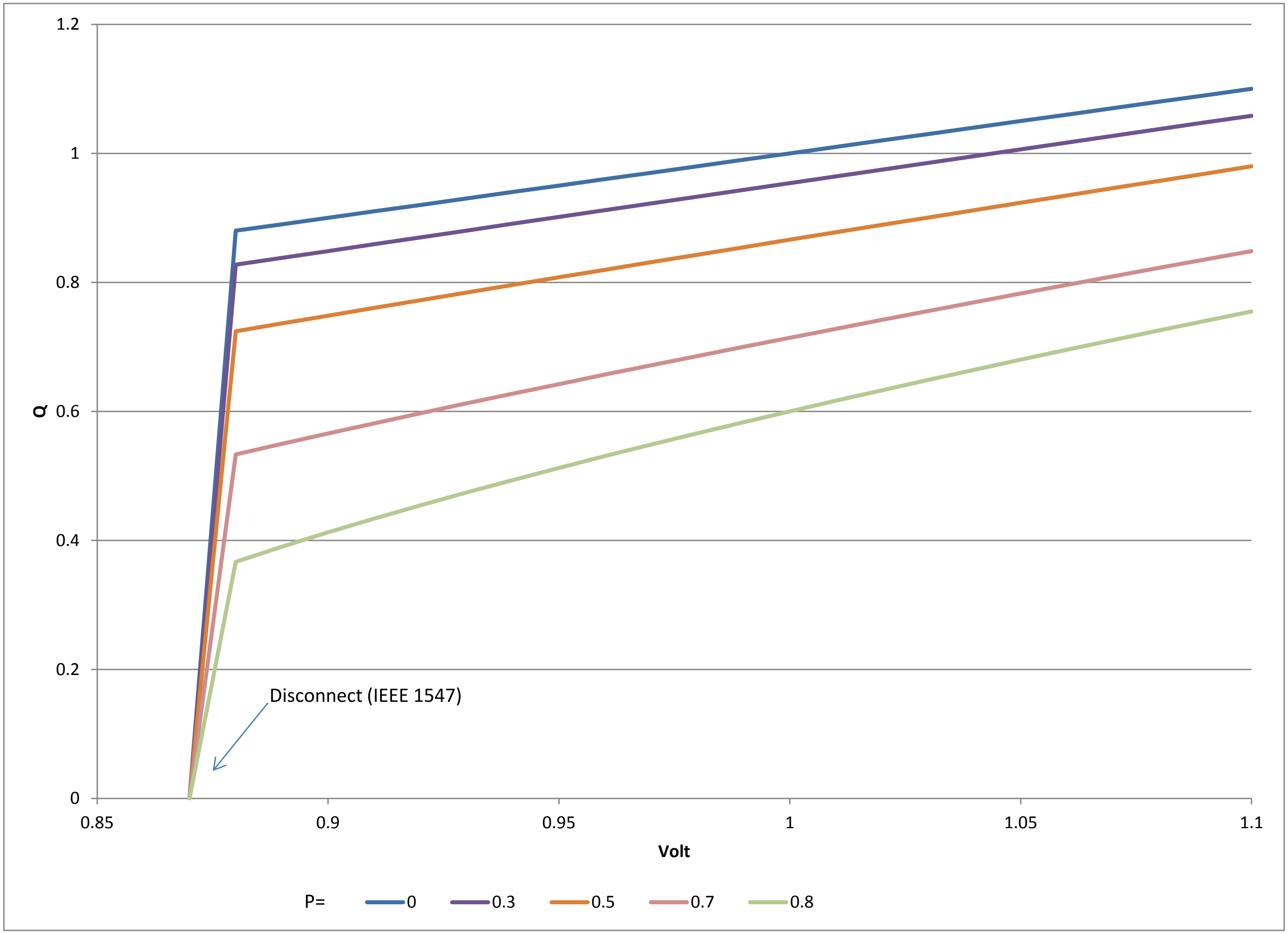


Figure 23. Reactive generation-to-voltage dependency of an inverter-based DER with Q=max mode of operations

The dependencies illustrated above are individual nodal load dependencies on the local voltage. The aggregated at the transmission bus dependencies are referenced to the transmission bus voltage. The local nodal voltages along the feeder are different under the same bus voltage due to the voltage drop along the feeders. Therefore, the voltage ranges of the load-to-voltage dependencies which are summed to be aggregated are different for different nodal loads (Figure 24). The reactive load dependencies are also different under different real power generated by the DERs. Figure 25 and Figure 26 illustrate the individual loads vs the voltage at the bus of aggregation. The modes of DER operations in this case are maximum reactive power (either generating, or absorbing). Figure 27 illustrates the aggregated load-to-voltage dependencies. As follows from the figures, the individual and the aggregated dependencies are different, when the modes of DER operations are different, when the voltage drop along the feeder is different, when the real power injections are different, when the ratio of the DER power to the natural load is different, etc. **Hence, every time one or more of these condition changes, the dependencies should be recalculated. (For instance, when feeder capacitors are switched ON or OFF, the voltage profile along the feeder changes, ant the load-to-voltage dependencies also change).**

Figure 28 through Figure 30 illustrate the real load dependencies on voltage. As seen in the figures, the dependencies can significantly differ under different weather conditions.

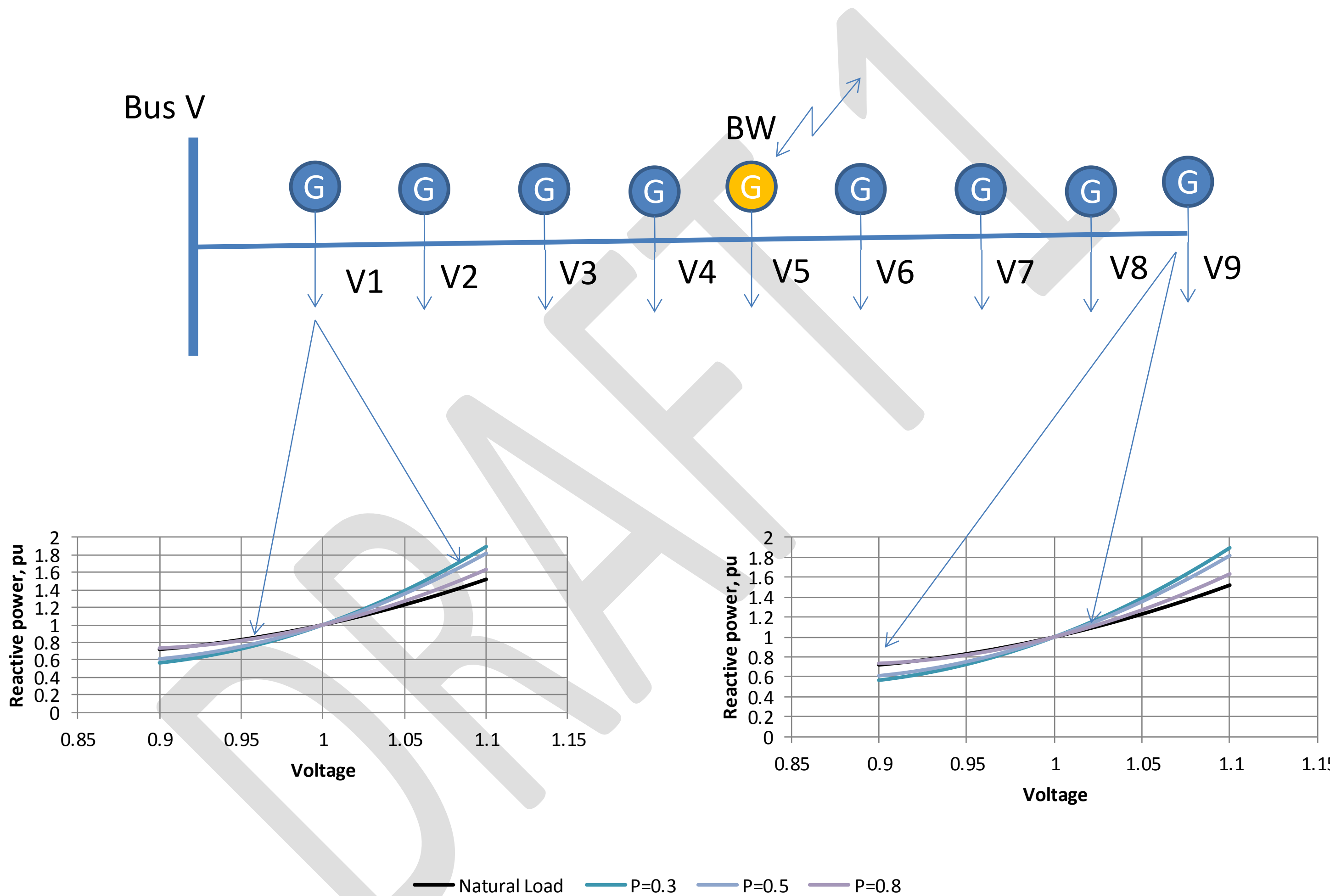


Figure 24. Nodal voltages are different along the feeder. Hence, different voltage ranges of the individual dependencies are used. The reactive load dependencies are different for different injections of real power by the DER.

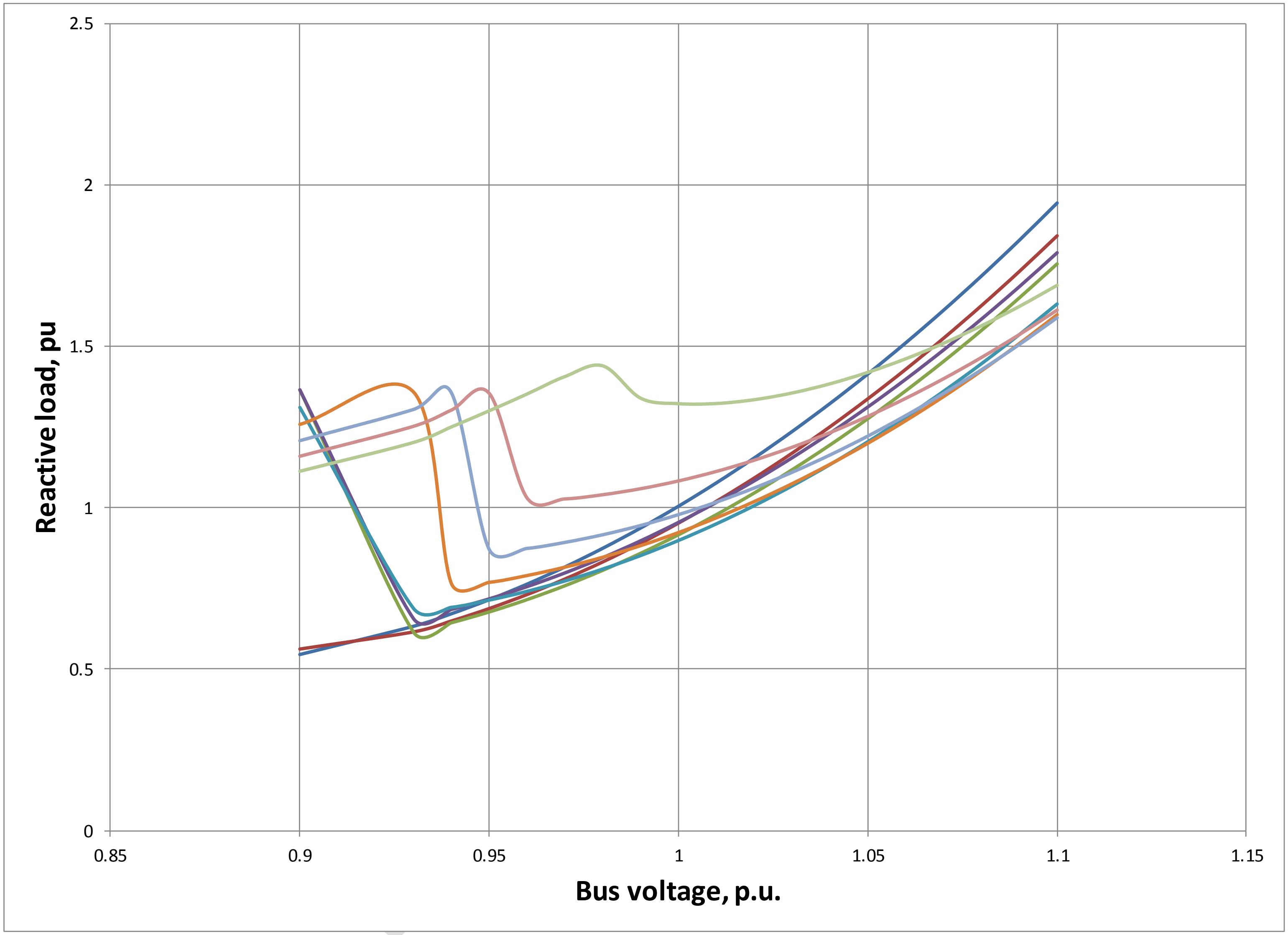


Figure 25. Individual nodal reactive load dependencies on bus voltage with embedded DER in generating mode. Mode of DER operation: Maximum reactive power according to the capability curve.

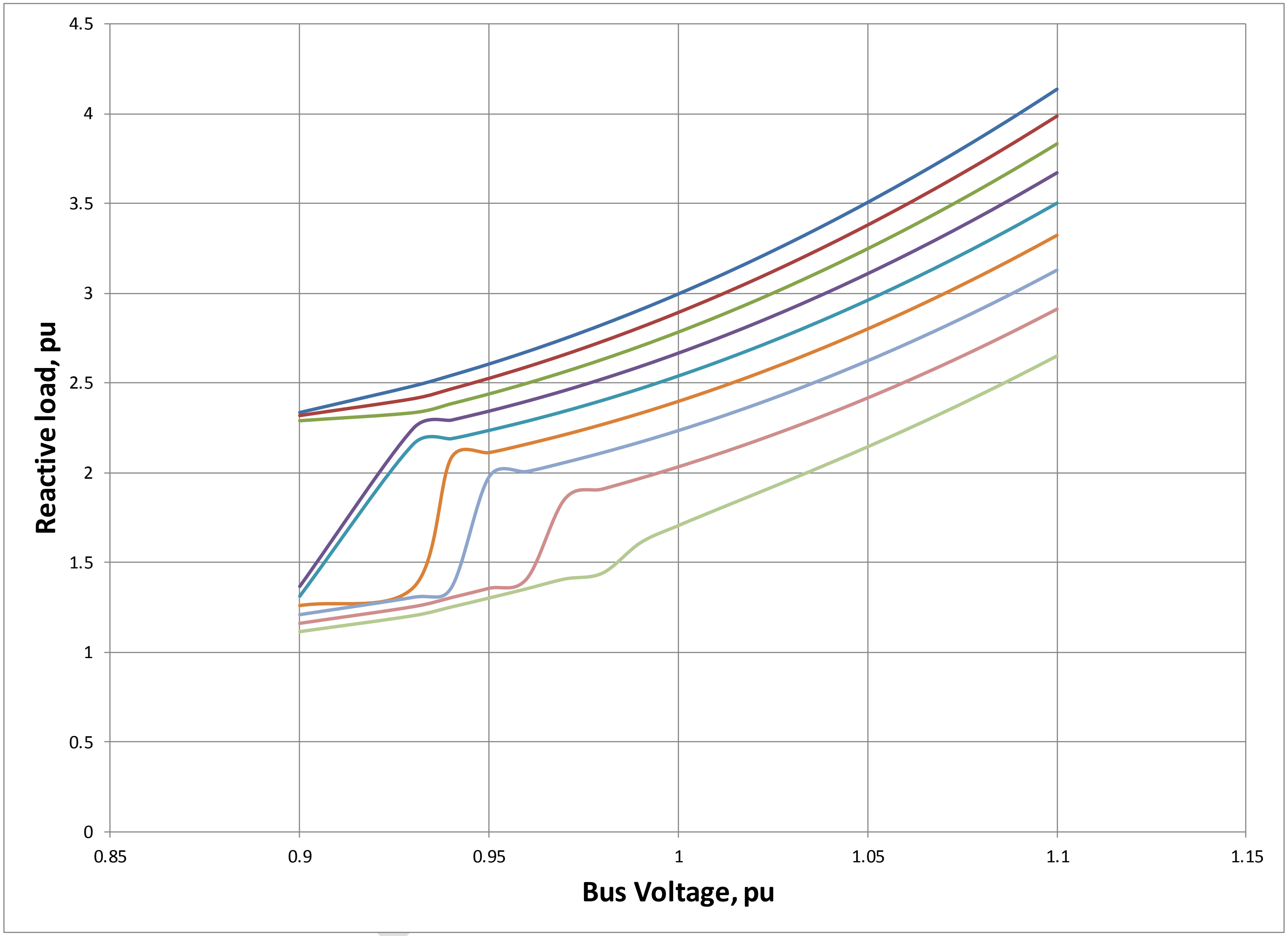


Figure 26. Individual nodal reactive load dependencies on bus voltage with embedded DER in absorbing mode. Mode of DER operation: Maximum reactive power according to the capability curve.

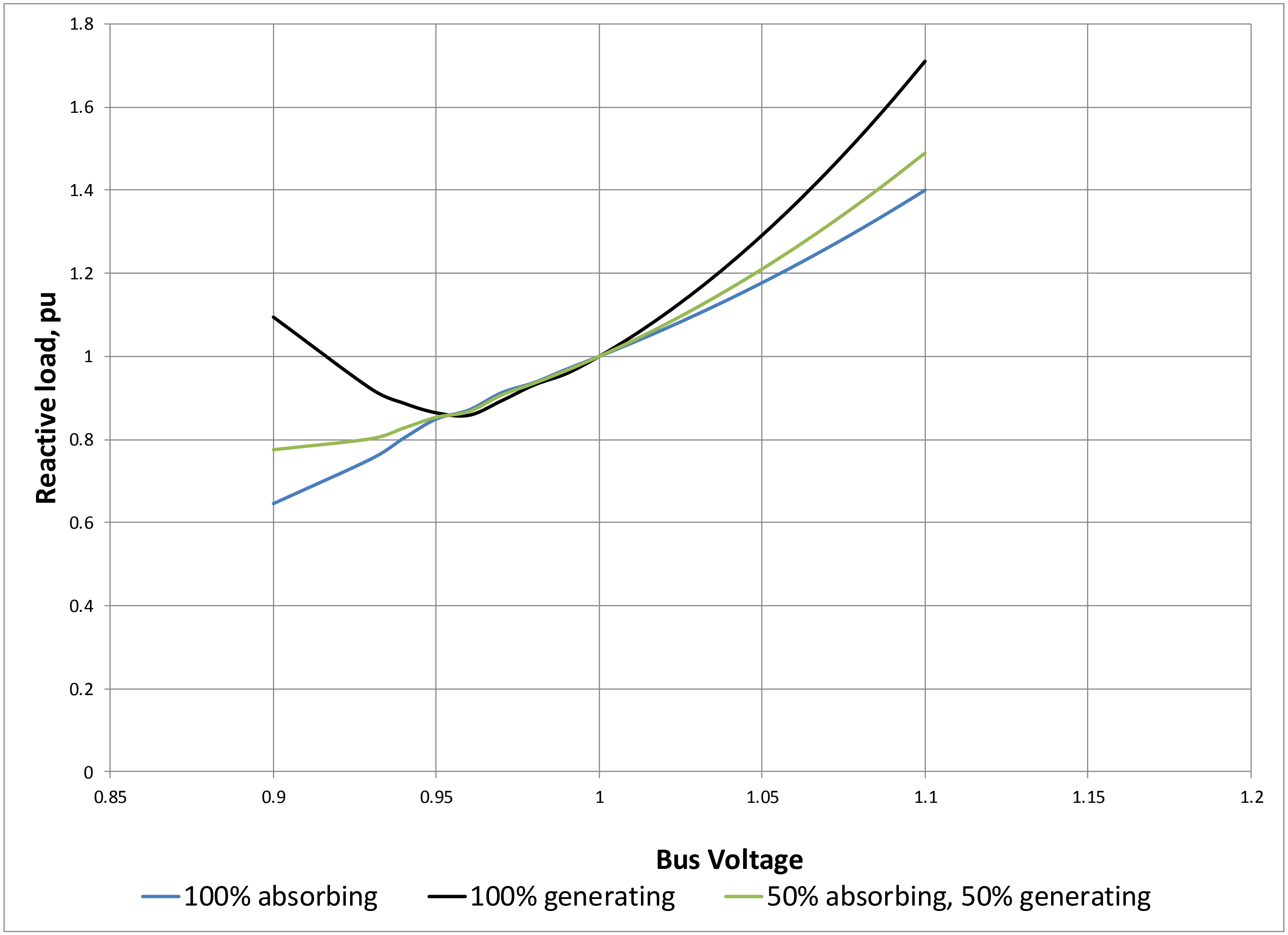
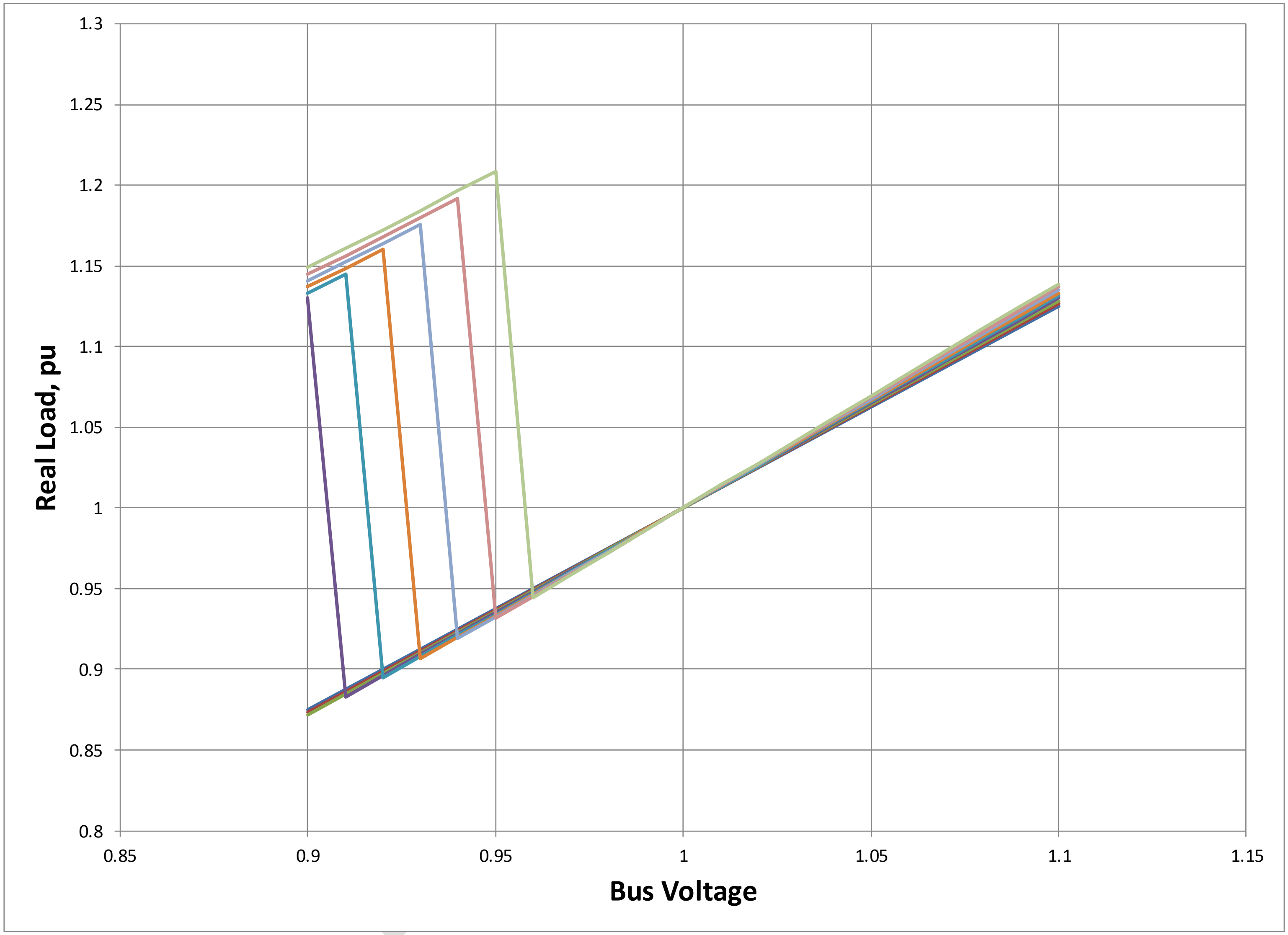


Figure 27. Aggregated at the bus load-to-voltage dependencies. Mode of DERs operation: Maximum reactive power according to the capability curve.



1
2 **Figure 28. Individual nodal active load dependencies on bus voltage with embedded DER**

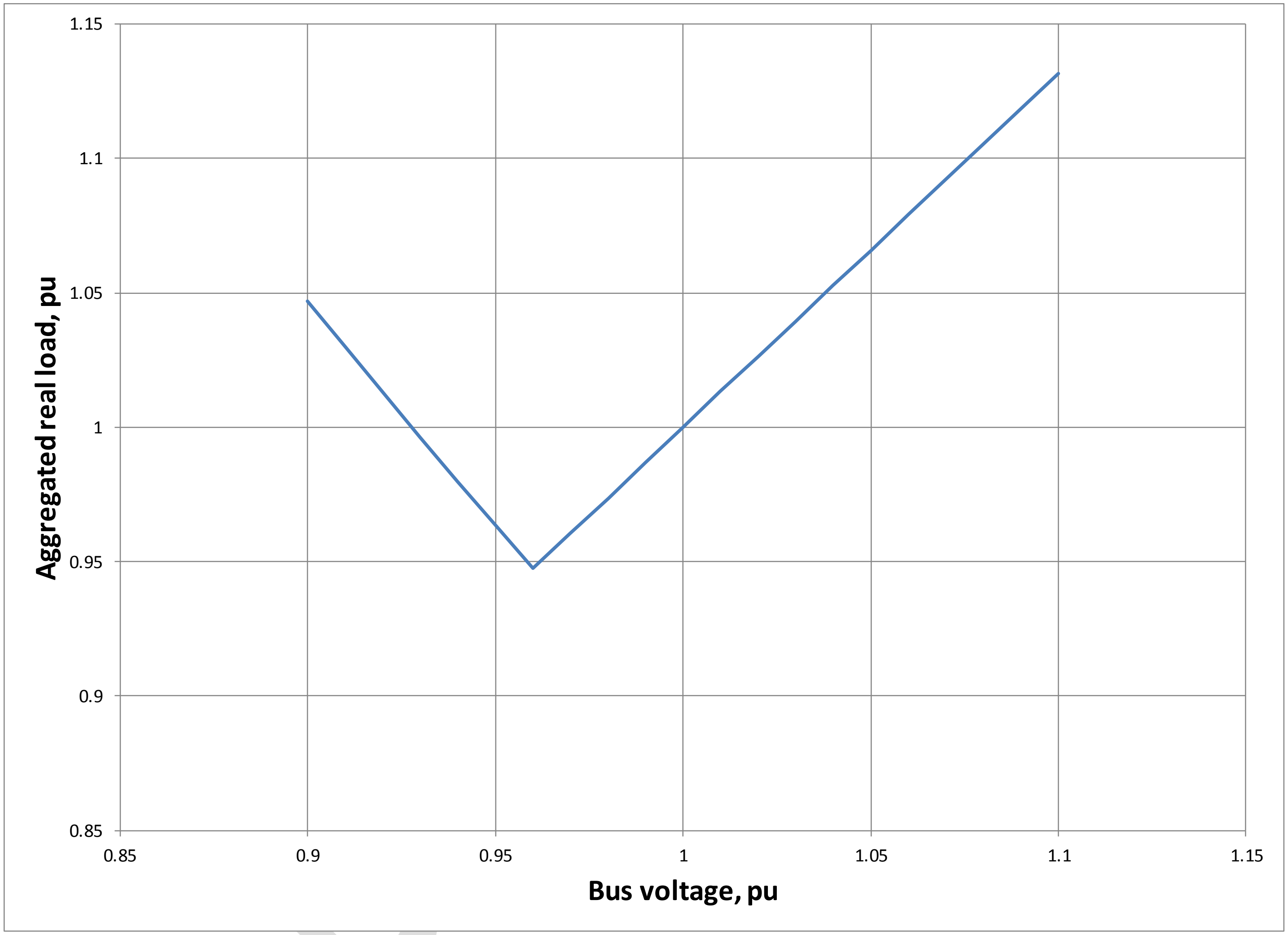


Figure 29. Aggregated at the bus real load-to-voltage dependencies, clear sky

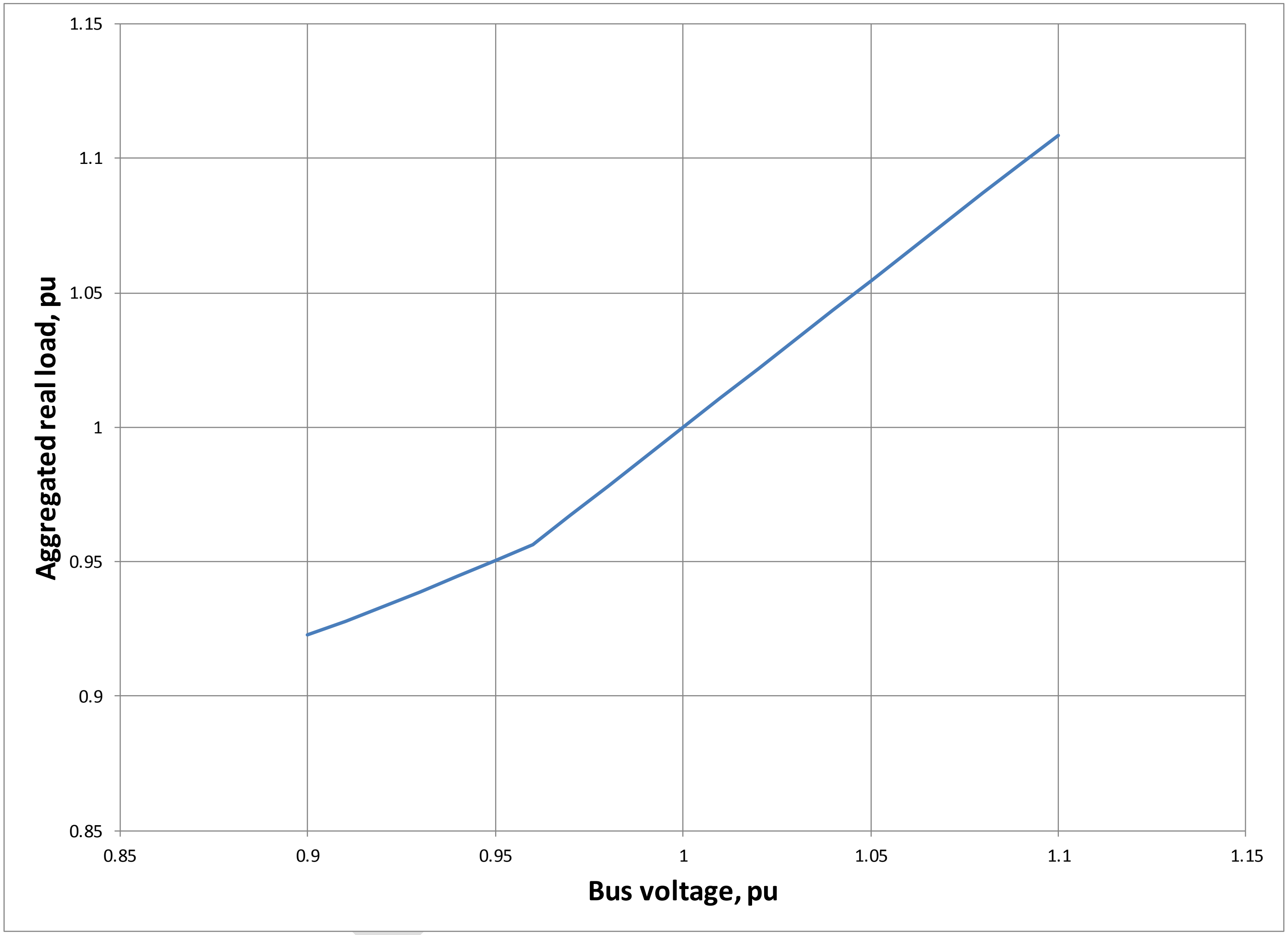


Figure 30. Aggregated at the bus real load-to-voltage dependencies, cloudy sky

The above considerations address the immediate aggregated load-to-voltage dependencies, i.e., before the voltage controlling devices in distribution operated. The voltages at the distribution bus and along the distribution feeders are different after the voltage-controlling devices change their statuses according to their setpoints. After that happens, the aggregated load will change and the steady-state load-to-voltage dependencies will be different from the immediate ones. However, the changes of the component of the aggregated load due to DER voltage protection will remain for a longer while until the DER are connected again to the grid. Other components, such as the natural load and the DER var control capabilities, will change according to the steady-state voltages. **Hence, the steady-state and the immediate load-to-voltage dependencies are not independent.**

The steady-state voltages at the distribution buses are different depending on the available range of the controlling devices and on their setpoints. Figure 31 illustrates the distribution bus voltages after the LTC operated for different available ranges of LTC control (boost) and different setpoints of the LTC controller. These parameters may change in near-real time depending on the operating conditions in transmission and on the performance of the DMS applications. The time for the steady-state dependencies to stabilize depends on the time delays of the voltage controlling devices and DMS applications.

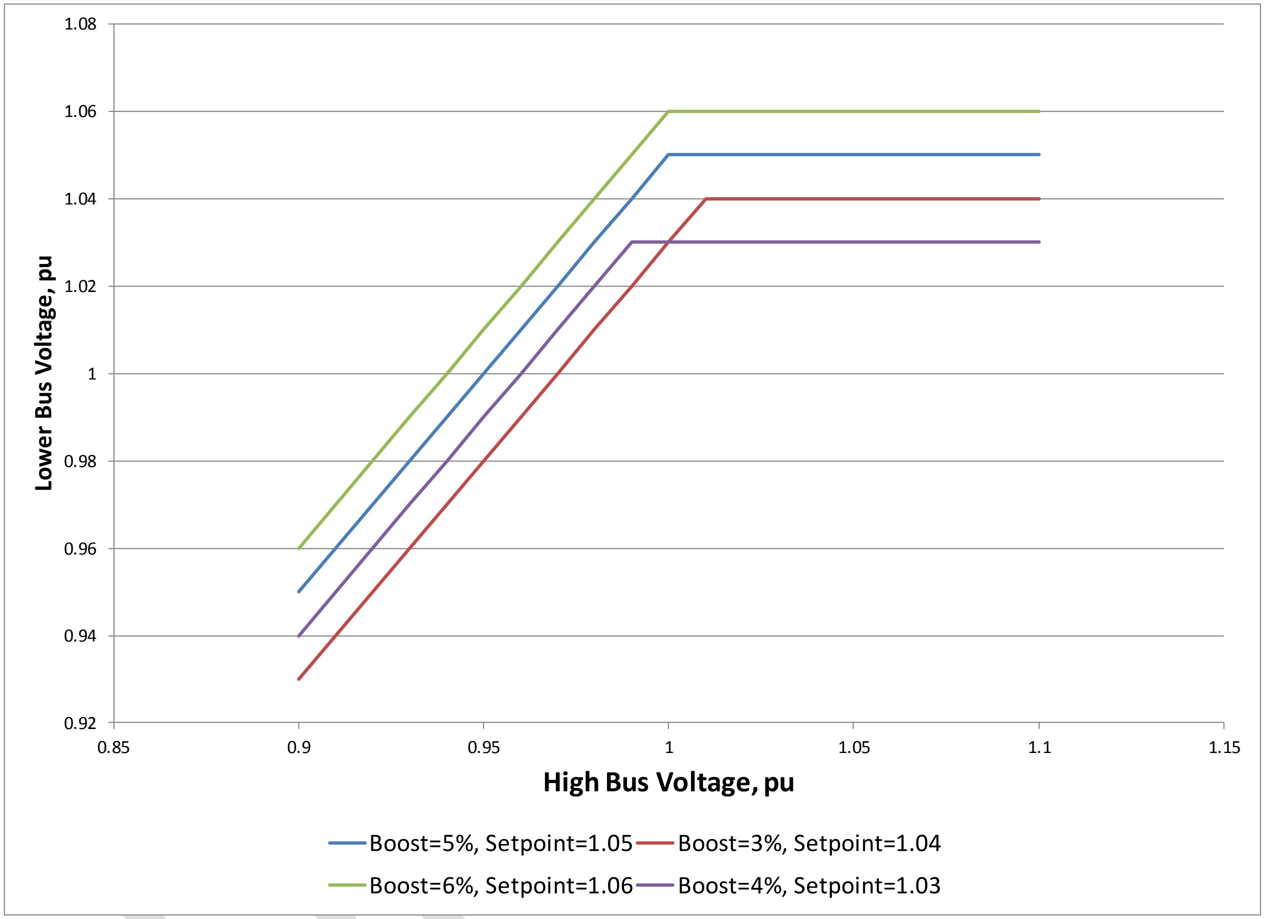


Figure 31. Voltages at the distribution bus after the LTC operated

Scenario 4. According to IEEE 1547™-2003, there are two groups of DER with different frequency protection requirements. The DER that are <30 kW should disconnect when the frequency is either below 59.3 Hz, or above 60.5 Hz within 0.16 sec. The DER that are >30 kW should disconnect when the frequency is either below 59.8 – 57 Hz within 0.16-300 sec, or is above 60.5 Hz within 0.16 sec. The natural load also depends on frequency with one through three percent of load change per percent of frequency change.

Figure 32 thorough Figure 34 illustrates the load-to-frequency dependencies. It is assumed in the illustrations below that the DER generation does not depend on frequency, which in reality may not be the case.

As seen in the figures, the dependency of the aggregated load, which includes DER generation, significantly differs from the dependencies of the loads without DER. The dependencies are also different for different DER protection setting, for different DER penetration (compare Figure 33 and Figure 35), for different times of the day, and for different weather conditions.

01-25-2

Because of the possible different time delays for the under-frequency protection of the DER with >30 kW, the load-to-frequency dependencies may be different for different time frames (compare Figure 33 and Figure 34).

In case of the micro-grids, the load-to-frequency dependencies will be different depending on the setup of the frequency protection:

- The protection is placed at the point of common coupling (PCC) separating the entire micro-grid from the EPS and at the connection points of the DERs inside of the micro-grid, with different priorities of actions.
- The protection is placed at the connection points of the DERs inside of the micro-grid only
- In addition, there are under-frequency load shedding schemes within the micro-grid.

In the case of separation of the micro-grids under abnormal frequency, the aggregated load-to-frequency dependencies are also dependent on the balance of the load and generation in the micro-grid while connected to the EPS.

The listed above differences may critically impact the development of emergency situation in the power system, and may require different preventive and corrective measures, including re-coordination of DER/micro-grid protection settings.

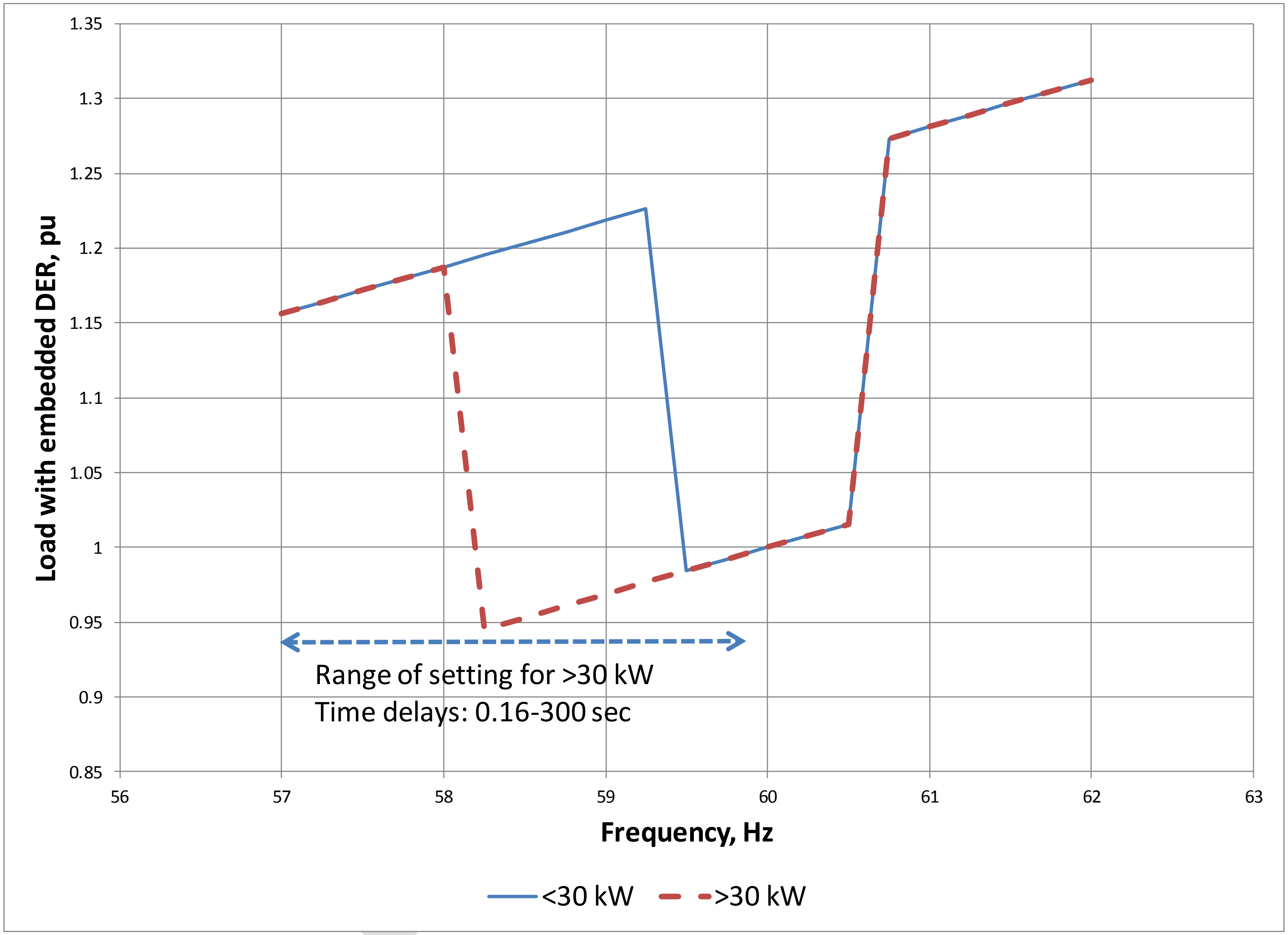


Figure 32. . Individual nodal active load dependencies on frequency with embedded DER

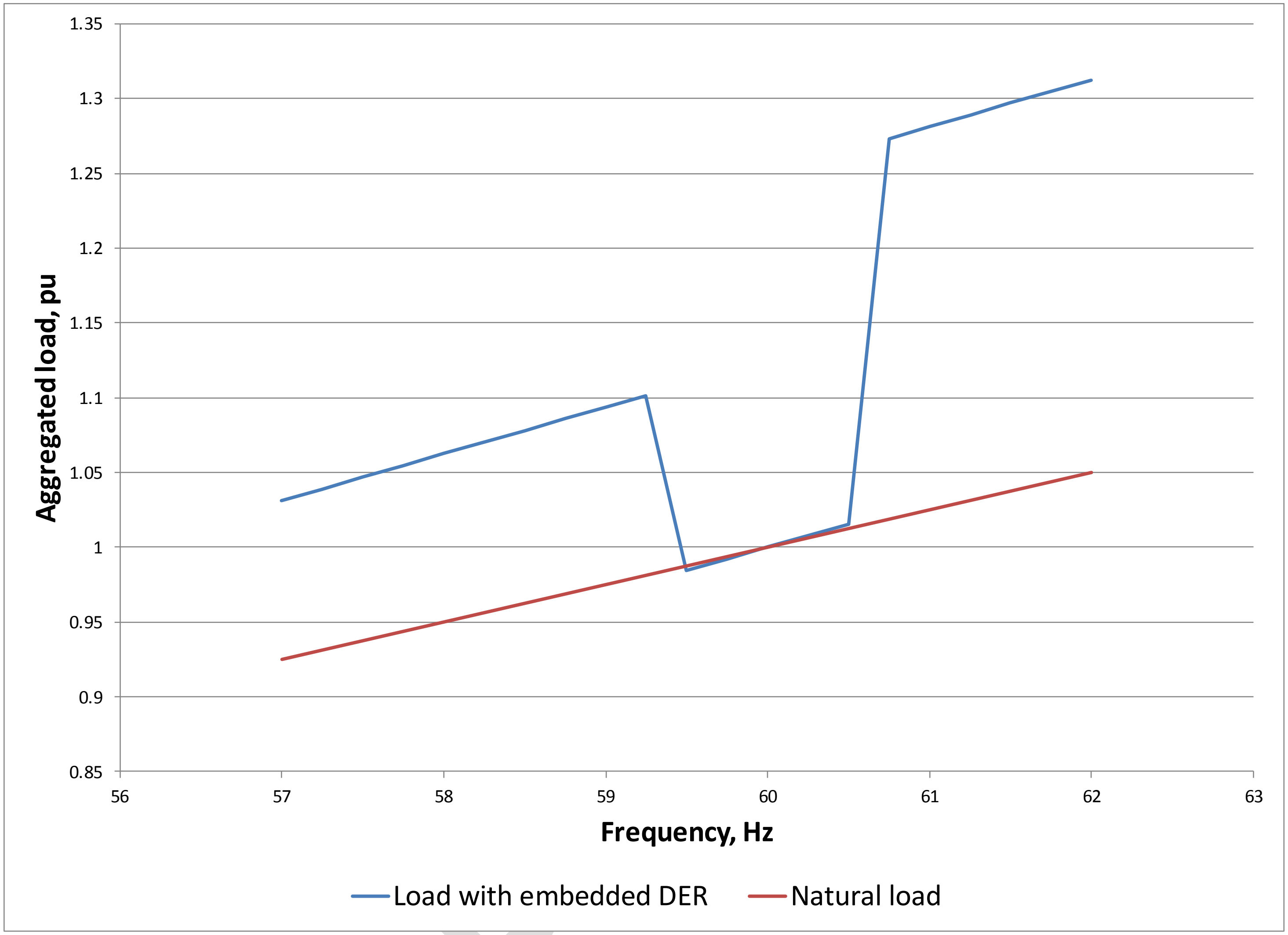


Figure 33. Aggregated at the bus real load-to-frequency dependencies, clear sky, before the time delay for >30 kW

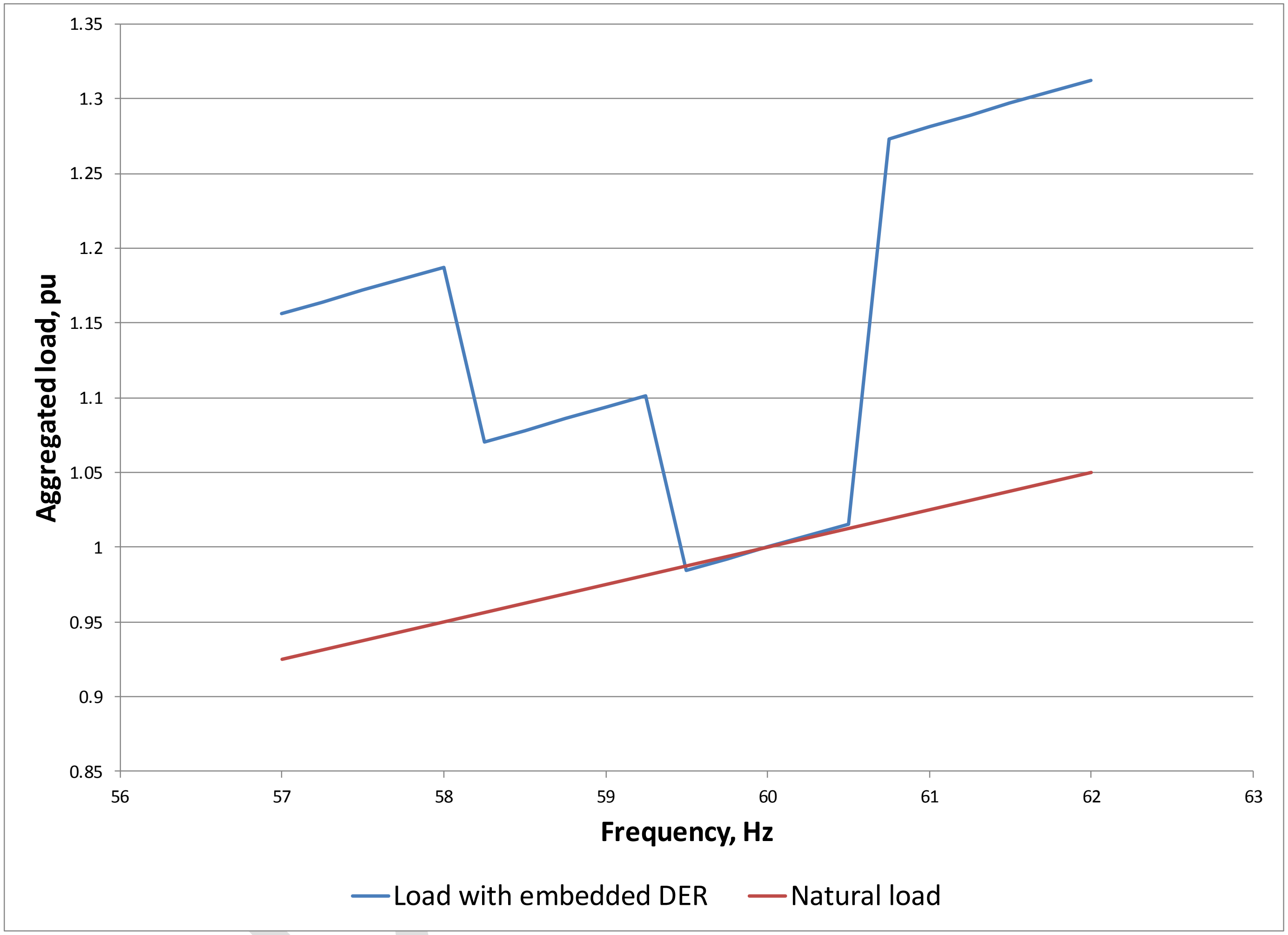


Figure 34. Aggregated at the bus real load-to-frequency dependencies, clear sky, after the time delay for >30 kW

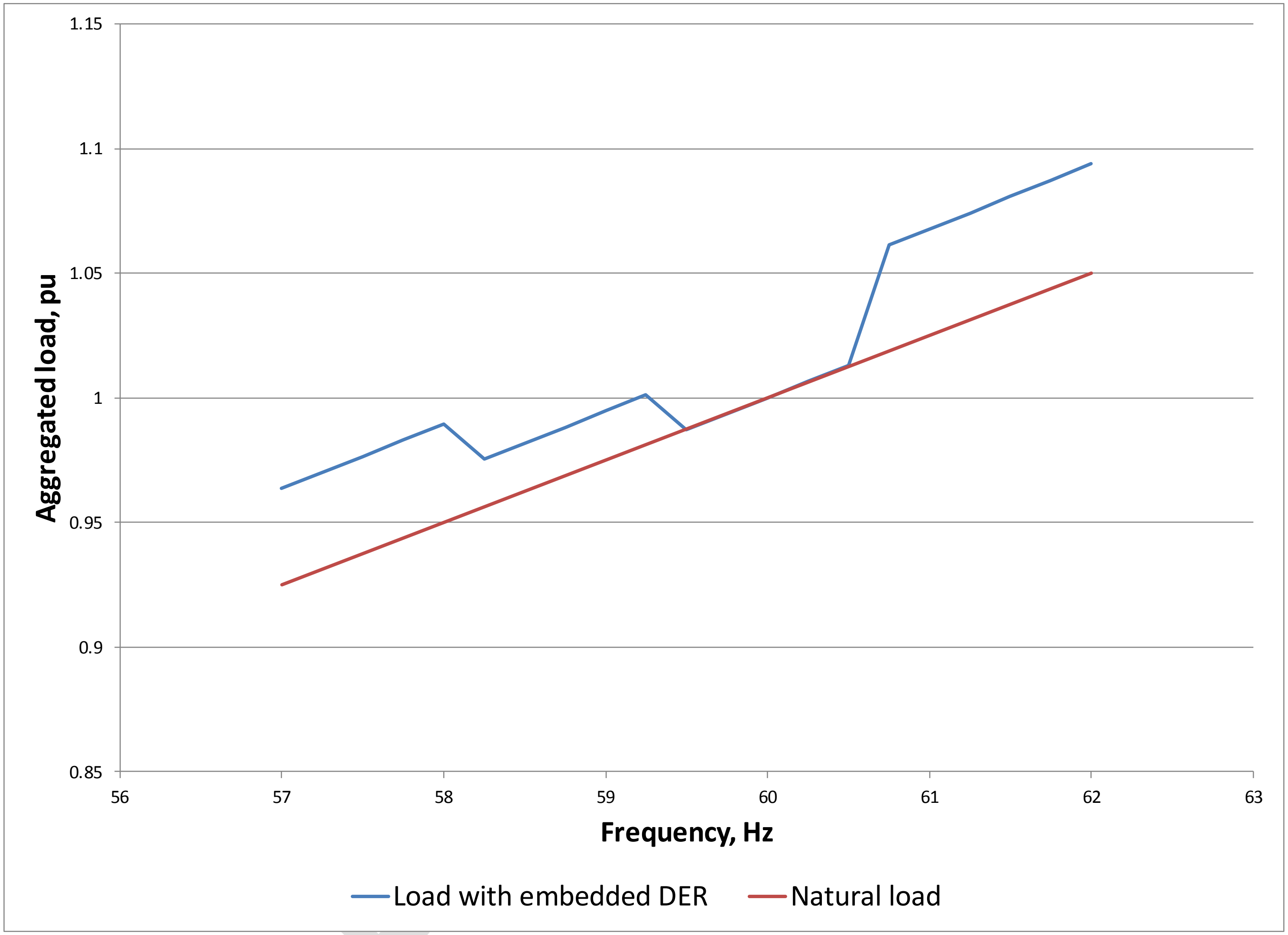


Figure 35. Aggregated at the bus real load-to-frequency dependencies, cloudy sky

01-25-3

The discussion above addresses the natural load and the DER/micro-grid components of the aggregated load-to-voltage/frequency dependencies. In addition to the load and DER changes due to voltage and frequency changes, there may be **Under-Frequency and Under-Voltage Load Shedding schemes (UFLS and UVLS) located in the distribution domain**. These schemes may either disconnect on per feeder/bus basis (in this case both the load and the DER would be disconnected, <u>and the information source can be the substation controller</u>), or they may disconnect portions of loads along feeders leaving the feeder connected, <u>and the information source can be a field IED</u>. The aggregated load connected to different schemes and groups of the schemes (a group is distinguished by different settings) is changing depending on the natural changes of the load, on the enabled Demand Response, and on the changes of the DER injections. Figure 36 presents an illustration of a aggregated load-to-frequency dependency based on combined impacts of DER frequency protection and UFLS operations. The DER impacts and the UFLS impacts on the aggregated loads may materialize at different times, depending on the time delays of the schemes and on the dynamics of the frequency. A similar illustration can be derived for the combination of DER voltage protection and UVLS operations.

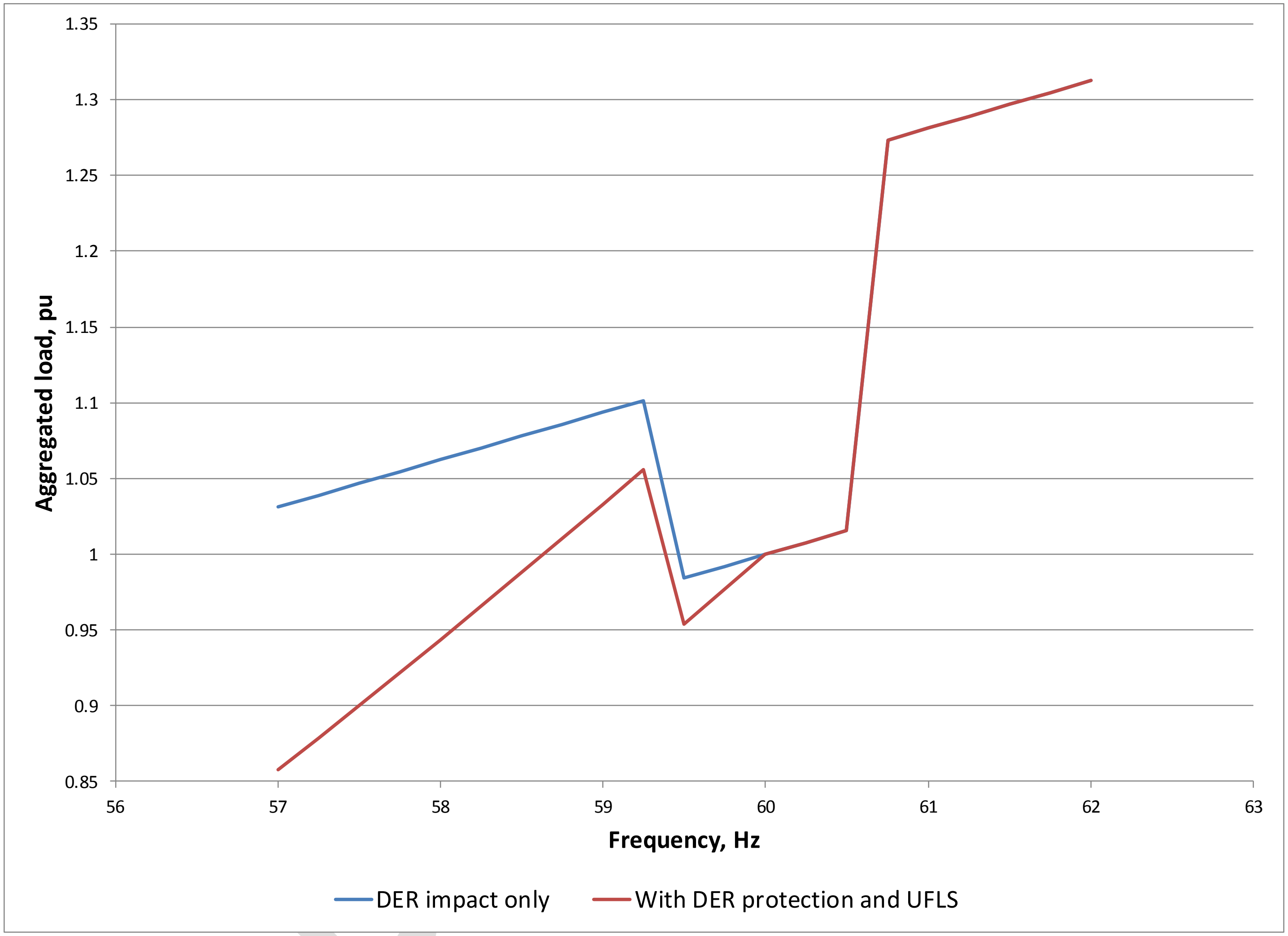


Figure 36. Aggregated load dependency on frequency based on DER frequency protection and on the operations of the UFLS

01-25-4

The above discussions and illustrations relate to either the change of bus voltage, when the frequency is constant, or to the change of frequency, when the bus voltage is constant. The model becomes more complex, when both the bus voltage and the frequency change. Figure 37 illustrates a combined load-to-voltage&frequency dependency for the natural load (without embedded DER).

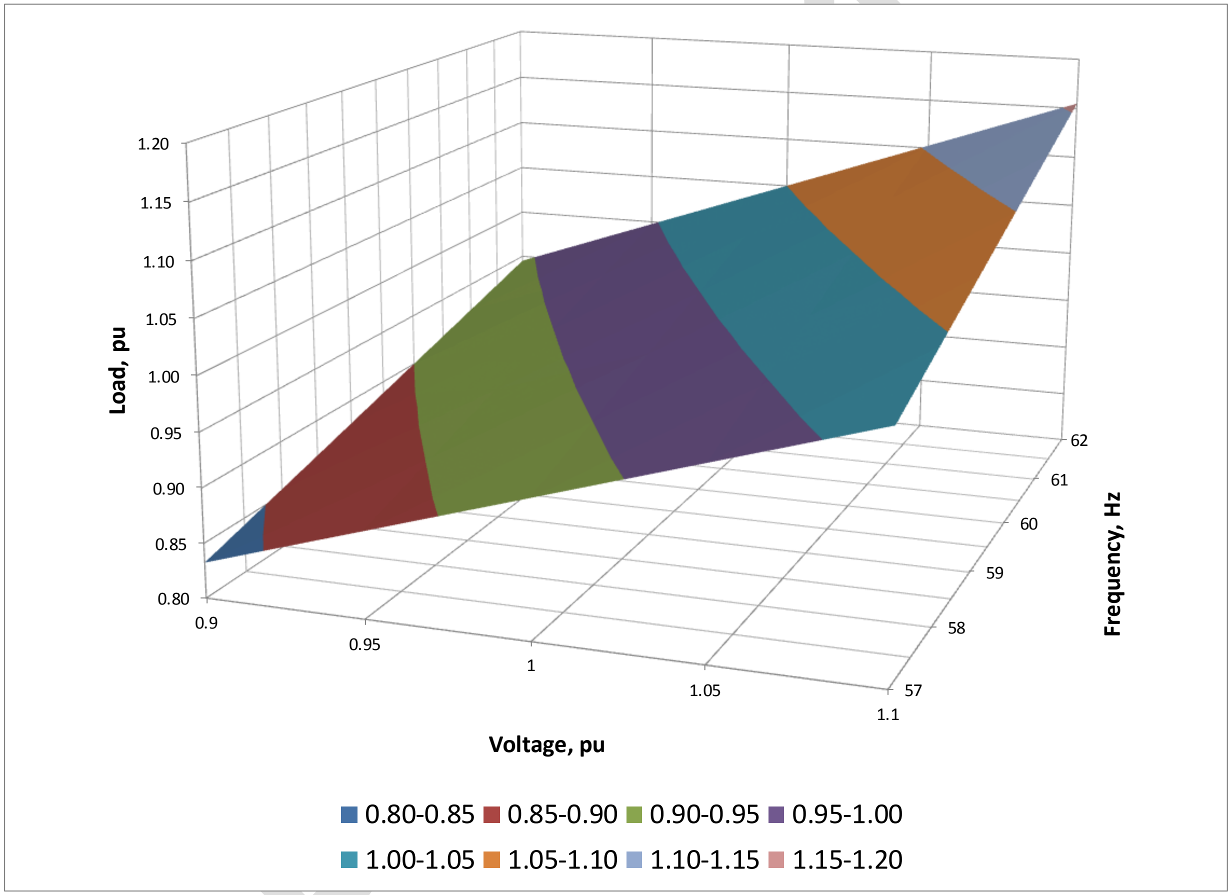


Figure 37. Combined natural load-to-voltage&frequency dependency

This is a three-dimensional dependency that can be presented as a table (Table 6) or an equation (e.g., (1)).

Table 6. Combined natural load-to-voltage&frequency dependency

		Voltage, pu				
		0.9	0.95	1	1.05	1.1
Frequency, Hz	57	0.83	0.88	0.93	0.97	1.02
	58	0.86	0.90	0.95	1.00	1.05
	59	0.88	0.93	0.98	1.02	1.07
	60	0.90	0.95	1.00	1.05	1.10
	61	0.92	0.97	1.03	1.08	1.13
	62	0.95	1.00	1.05	1.10	1.16

$$Load(f,V) = Nominal\ Load\ \times (1 - (60 - f) \times \frac{dLoad,pu}{df,Hz} \times (1 - (Vnom - V)/Vnom \times \frac{dLoad,pu}{dV,pu}) \quad (1)$$

When it comes to the performance of the DER protection and Remedial Action Schemes (RAS), additional factors become involved:

- The participation of the same loads in different RAS
- The overlapping of the voltage and frequency protection of DER
- The time delays of the protection and the RAS.

The use case addressing the participation of the same loads in different RAS and the overlapping of the voltage and frequency protection of DER are described later in Scenario 9.

According to IEEE 1547™ -2003, the time delays of DER voltage protection are 2 sec, if the voltage is below 88%, and 0.16 sec, if the voltage is either below 50%, or above 120%. The time delays for the frequency protection are 0.16 sec for DER with <30 kW, when the frequency is either below 59.3 Hz, or above 60.5 Hz. For the DER with >30 kW, the time delays can be within 0.16 sec through 300 sec, and the frequency settings below a setpoint within 59.8 Hz through 57 Hz.

The UFLS and UVLS RAS also have different time delays for different groups.

Hence, in addition to the voltage and frequency dimensions, there is another dimension in the aggregated load model – the time delays of the RAS and DER protection.

Therefore, the TBLM shall represent the load as a combination of load groups with and without embedded DER, which differ by the value and time settings of DER protection and RAS. The overlapping portions of the load connected to the RAS and of the DER injections under the voltage and frequency protection (the same DER can be disconnected either by the voltage protection or by a specific group of frequency protection, whatever works first).

At the present times, the protection and RAS settings typically are conditionally constant values, i.e., they are not changed often and can be attributes residing in corresponding corporate Data Management Systems (databases). The same can be said about the circuits connected to each group of RAS.

Under the Smart Grid conditions, a near-real time adaptation of the DER protection and RAS settings and the connected facilities may be needed for the self-healing power systems. In this case, these attributes of the RAS and DER object models will need to be controlled and monitored via communications with the field devices.

An example can be discussed based on the diagram in Figure 4.

If a load-rich island is created and the RAS started shedding load and some DER are staring disconnecting, the power flow may change into one, which results either in bad voltage, or in overload of internal lines, or both. This would depend on the load-generation balance in different areas of the island. For instance, if Area 1 was initially short in generation, then after separation of the island, area 1 will try to draw supply from area 2, if there is available generation. The generation in Area 2 can become available, if the UFLS sheds the load in Area 2 faster than in Area 1, and/or if the DER disconnect faster in Area 1 than in Area 2. The flow of power from Area 2 into Area 1 may further reduce the voltage in Area 1 or overload the tie-line, and result in even greater loss of local generation. In this case, the load shedding by the RAS should happen faster in Area 1 than in Area 2, and the DER protection in Area 1 should have longer time delays.

If the load-rich area is Area 2, the opposite priorities of the RAS operations and DER protection will be needed. The load-generation balances of the different power system areas may change at any time. **It means that the preventive measures for the self-healing performance of the emergency control system should also adapt in near-real time, and the TBLM should be updated correspondingly.**

Another example can be discussed based on micro-grids in distribution. Let's consider a number of situations as presented in Table 7. As seen in the table, the conditions for the prioritization and sizing of the RAS and DER protection for micro-grids may also change in near-real time , and, therefore, the settings should be accordingly adapted based on the micro-grid and EPS conditions, and the TBLM should be timely updated.

Table 7. Changing priorities of RAS and DER protection for Micro-grids

Load-generation balance of the Micro-grid		EPS Operator's interest under emergency conditions	Micro-grid operator's interest under emergency conditions
Micro-grid is load-rich	Micro-grid is connected to EPS. The load import is greater than the UFLS in the micro-grid	Assign higher priorities to the UFLS within the micro-grid and lower ones to the PCC. Keep the DER protection priorities even lower.	Assign higher priorities to the UFLS within the micro-grid and lower ones to the PCC. Have another load-shedding RAS for balancing load under island conditions
	Micro-grid is connected to EPS. The load import is smaller than the UFLS in the micro-grid	Assign priorities to the UFLS within the micro-grid according to the EPS rules (interconnection contracts) and no UFLS for the PCC (after UFLS the MC will inject in the EPS)	Assign higher priorities to the UFLS for the PCC and lower for the UFLS within the micro-grid
Micro-grid is generation-rich	Micro-grid is connected to EPS. The micro-grid injects power into EPS.	Assign priorities to the UFLS within the micro-grid with higher priorities than the DER frequency protection. No UFLS for the PCC.	UFLS for the PCC only with higher priority than the DER frequency protection.

Preconditions: Load modeling processor and DER modeling processors are operational. The local weather conditions, like clear sky, clouds, and intermittent clouds are reported either by local weather stations, or by bellwether Smart Meters. The weather information obtained via the Smart Meters may be derived by the AMI Data Management System processing pattern- recognition-like procedure over the near-real time measurements from the bellwether meters. Substation Automation provides snapshots to the DMS scheduler with substation LTC and capacitor controller settings, with the LTC tap position and capacitor statuses, with UFLS and UVLS group settings and connected feeders. It can also execute controls of these devices from the DMS applications. Distribution SCADA provides similar information and control capabilities from the field devices, including large DER and micro-grid controllers, including aggregated data for the micro-grid (e.g., internal UFLS, UVLS, and DER protection parameters), AMI provides connect-disconnect capabilities for load shedding.

Table 8. Step-by-step actions for for Scenarios 3 and 4

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
#	Triggering event? Identify the name of the event.3	What other actors are primarily responsible for the Process/Activity? Actors are defined in section2.	Label that would appear in a process diagram. Use action verbs when naming activity.	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.	What other actors are primarily responsible for Producing the information? Actors are defined in section2.	What other actors are primarily responsible for Receiving the information? Actors are defined in section2. (Note – May leave blank if same as Primary Actor)	Name of the information object. Information objects are defined in section 3	Elaborate architectural issues using attached spreadsheet. Use this column to elaborate details that aren't captured in the spreadsheet.	Reference the applicable IECSA Environment containing this data exchange. Only one environment per step.
1.1	Periodic or by-event trigger of DOMA	DMS Scheduler	Trigger of DOMA	Start periodic or by-event run of DOMA based on the last snapshot of input data	DMS Scheduler	DOMA application	DOMA start		
2.1	DOMA enabled	DOMA	DOMA collects data from the Load Modeling Processor	DOMA updates adaptable load models, if needed	Load Modeling Processor	DOMA applications	Updates of adaptable load models		

[3] Note – A triggering event is not necessary if the completion of the prior step – leads to the transition of the following step.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
2.2	DOMA enabled	DOMA	DOMA collects data from the DER Data Management System	DOMA updates the adaptable DER models	DER Data Management System	DOMA applications	Updates of adaptable DER models		
2.3	DOMA enabled	DOMA	DOMA collects data from the Load Management System	DOMA updates the states of Demand Response	Load Management System	DOMA applications	Updates of the states of Demand Response	If the Demand Response is enabled, the load composition of the participating customers is changed, and the individual load-to-voltage dependencies may be different.	
3	All background data is collected by DOMA	DOMA	DOMA collects data from the last snapshot provided by the DMS scheduler	DOMA updates the status and analog data from DSCADA, EMS, Weather System, and Market systems collected by the DMS scheduler	DMS scheduler	DOMA	Updates of near-real-time input data		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
4	All input data is collected by DOMA	DOMA	DOMA adapts the load, DER/micro-grid, volt/var controlling devices and RAS models based on the collected data	DOMA updates the topology model based on status data, the load and DER models based on time of day, weather, and pricing data and balances the load models with DSCADA measurements by running the state estimation. DOMA updates the settings of controlling devices and RAS, and the facilities connected to the RAS	DOMA	DOMA	Adaptation of models and balancing the Load and DER injections		
5.1	Facility, topology, load and DER models adapted and balanced, state estimation and power flow calculations executed	DOMA	Adaptation of the individual near-real-time DER capabilities, controlling ranges of volt/var controllers, and RAS and DER protection parameters.	DOMA adapts the individual near-real-time DER capabilities based on the power flow results and current DER states. DOMA adapts the current and available state of volt/var controlling devices and the settings and load allocation for the RAS.	DOMA	TBLM developer	Near-real-time DER capabilities of individual and/or groups of DER. Near-real time parameters of controlling and protection devices.		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
5.2	Load and DER models adapted and balanced, state estimation and power flow calculations executed	DOMA	Provision of IVVWO with the updated reference model	DOMA provides IVVWO with the latest near-real time state estimation/power flow results and with the available modes of operation and ranges of volt/var controlling devices	DOMA	IVVWO	IVVO reference model		
6.1	TBLM developer received near-real time DER capabilities, modes of operations and settings of the controlling and protection devices	TBLM developer	Consolidation of current individual load/DER dependencies on voltage and frequency into immediate aggregated dependencies	The individual current Load/DER dependencies are aggregated into transmission bus dependencies by running a series of dynamic voltage/frequency calculations covering the emergency and normal voltage/frequency ranges (it may be either default range of voltages (including emergency levels), or ranges of possible voltages based on EMS contingency analyses).	TBLM developer	TBLM	Aggregated Load-to-volt/Hz dependencies for dynamic studies		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
6.2	TBLM developer received near-real time DER capabilities, modes of operations and settings of the controlling and protection devices	TBLM developer	Consolidation of current individual load/DER dependencies on voltage and frequency into steady-state aggregated dependencies	The individual current Load/DER dependencies are aggregated into transmission bus dependencies by running a series of steady-state power-flow-like calculations for a set of given frequencies, covering the emergency and normal voltage/frequency ranges (it may be either default range of voltages (including emergency levels), or ranges of possible voltages based on EMS contingency analyses).	TBLM developer	TBLM	Aggregated Load-to-volt/Hz dependencies for steady- state studies, before IVVO starts running		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
6.2	TBLM developer received near-real time DER capabilities, modes of operations and settings of the controlling and protection devices	TBLM developer	Initiating the "what-if" studies by the IVVWO under a wide range of transmission bus voltages for a given set of frequencies	TBLM developer initiates the IVVWO and provides it with either default range of voltages (including emergency levels), or ranges of possible voltages based on EMS contingency analyses.	TBLM developer	IVVWO	Enabling IVVWO within given voltage ranges at the transmission bus.	If there is no IVVWO, the "what-if" studies should be performed by DOMA taking into account the existing volt/var control system	
7	IVVWO received the initiation signal and the operational ranges from the TBLM developer	IVVWO	IVVWO runs the "want-if" studies with different transmission bus voltages.	IVVWO runs the "what –if" studies under the current IVVWO objective and derives the total load at the transmission bus for each transmission bus voltage. These arrays of data are provided to the TBLM developer.	IVVWO	TBLM developer	Load-to-transmission bus voltage dependence arrays with the impact of IVVO	The IVVWO can be run with different normal objectives. In this case, the load-to-voltage dependencies will also be dependent on the objective.	

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
8.1	TBLM developer received the results of IVVWO "what-if" studies.	TBLM developer	Aggregating the nodal load-to-voltage dependencies	The TBLM developer arranges the arrays into the accepted format for the TBLM.	TBLM developer	TBLM	Formatted aggregated load-to-voltage dependencies.		
1.2	The operations of significant DER or micro-grids are changed (due to time, or weather conditions), or the circuit connectivity, or the capacitor statuses are changed.	AMI Data Management system	A new pattern of the loads with DER is derived.	The AMI Data Management System received information from the bellwether meters that is recognized as a significantly new operational pattern in a particular local area. It derives the properties of load for this pattern (e.g., an average steady-state component and a random dispersion component)	AMI Data Management system	Load modeling Processor	New pattern for load model adaptation	For instance, clear sky is changed to intermittent cloudiness. The bellwether meters report fluctuations of the real load and opposite fluctuations of reactive loads. Based on this data, the AMI Data Management system derives a new pattern for all nodal loads in the relevant area.	

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
1.3	The operations of significant DERs or Micro-grids are changed (due to time, or weather conditions), or the circuit connectivity, or the capacitor statuses are changed	DER Data Management System	A new pattern of the DER operations is derived.	The DER Data Management System received information from the DER/micro-grid controllers that is recognized as a significantly new operational pattern in a particular local area. It derives the properties of DER/Micro-grid operations for this pattern (e.g., an average steady-state component and a random dispersion component) , or it changes the RAS and protection settings and allocations	DER Data Management system	DER modeling processor	New pattern for DER model adaptation		
1.4	DOMA triggered by event	Load model Processor	Trigger DOMA due to a significant change in the load patterns	Start run of DOMA by event based on the change of load input data	Load model Processor	DOMA application	DOMA start		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
1.5	DOMA triggered by event	DER model Processor	Trigger DOMA due to a significant change in the DER/Micro-grid operation patterns, protection setting and/or RAS allocation	Start run of DOMA by event based on the change of DER/Micro-grid input data	DER model Processor	DOMA application	DOMA start		
1.6	DOMA triggered by event	Topology Processor	Trigger DOMA due to a significant change in the circuit connectivity	Start run of DOMA by event based on the change of topology input data	Topology model Processor	DOMA application	DOMA start		
1.7	DOMA triggered by event	SCADA/ DSCADA	Trigger DOMA due to a significant change in the relevant RAS parameters	Start run of DOMA by event based on the change of RAS parameters	SCADA/ DSCADA	DOMA application	DOMA start		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
Back to 2.1, 2.2, 2.3, etc.									

Scenarios 5 and 6: Develop aggregated real and reactive load dependencies on Demand response control signals and on dynamic prices.

Scope. The demand response characteristics should be aggregated at the demarcation buses between the transmission and distribution domains. They should cover the normal and the emergency situations and should include the impacts of the customer-side demand response on the operational characteristics of the distribution system connected to the subject bus. The interrelationships between the Demand Response and other load management means, including RAS, should be represented in the TBLM. Various currently employed and future Demand Response programs should be included in the modeling.

Objectives. Provide available in near-real-time and in short-term look-ahead time intervals aggregated real and reactive Demand Response values and associated characteristics in the TBLM for the normal and emergency EMS applications.

Background Information

With high penetration of Demand response and other load management means, the dispatchable load in the active distribution network becomes a significant component in the operations of the transmission and generation domains. The “negawatts” in distribution can be used instead of expensive bulk generation megawatts, and they can assist in mitigating congestions and bulk power system emergencies.

However, the available load reduction aggregated at the transmission bus cannot be considered as one block of a resource. There is a variety of Demand Response programs in different utilities. For instance South California Edison has 13 different DR programs, and ten of them can be combined with one more program, which makes it 23 different programs [17]. It can be expected that new programs will be offered in the future. Each of these programs has different triggers, different incentives (cost), different time of engagement, durations of the response, different changes of the load reduction during the response time, etc.

Also, when the Demand Response is applied in different locations of the distribution system, it impacts the power flow, voltages, losses, and behavior of other DMS applications. Hence, the aggregated at the transmission bus load reduction is not just a sum of all local Demand Responses. It is the resultant change of the total load caused by the demand response, which should be determined by adequate simulations of all significant changes in distribution operations caused by the applied demand response.

The information needed for integration of the dispatchable distribution load into transmission and generation operations consist of the following characteristic:

- **Amount of available load**
- **Time needed for activation of the load reduction**
- **Available duration of the load reduction**
- **Cost of the load reduction**
- **Steadiness of the load reduction during the time of engagement**
- **Probability of execution.**

The duration of each individual demand response is limited. If the needed duration of the aggregated demand response is greater than the duration of one block of demand response, this block should be replaced with another block , etc. The attributes of the additional blocks of demand response may be different.

The total penetration of the demand response is also limited. It means that the greater is the duration of the aggregated demand response, the smaller is the available amount of load reduction at one time.

The following form of the aggregated at the transmission bus demand response is suggested as an illustration only of the information needed for the development of the DR component in the TBLM.

Table 9. Example form for aggregated Demand Response

DR Block	Nominal (Contractual) Amount, kW	Nominal (Contractual) time of activation	Duration	Change during commitment	Cost, $/kWh	Probability of implementation	Comments
Normal Conditions							
Integrated Load –reducing Volt/var Optimization (IVVO) within normal voltage limits	500	Up to 2 min	6 hours	±10%	0.04	90%	The customers adjust to the lower voltage
Integrated Volt/var/Watt Optimization (IVVWO) within normal voltage limits – includes demand response in voltage-critical point to increase the effectiveness of the IVVO.	**1500**	Up to 15 min	2 hours	Decay by 15%	0.55	85%	150 kW of Block 1 DR used
			4 hours	Decay by 15%	0.60	85%	300 kW of Block 1 DR used
			6 hours	Decay by 15%	0.70	85%	450 kW of Block 1 DR used

Block 1 of Demand response …	3000	Up to 20 min	2.0 hours	Decay by 15%	0.7	80%	2850-3000 kW of DR used
			4.0 hours	Decay by 15%	0.8	0.80%	5700- 6000 kW of DR used
			6.0 hours	Decay by 15%	0.9	0.80%	8550-9000 kW of DR used
Blok n of Demand Response	4000	Up to 45 min	2 hours	Decay by 15%	1.0	0.80%	4000 kW of DR used
			4 hours	Decay by 15%	1.0	0.80%	8000 kW of DR used
Emergency Conditions							
Block m of Demand response	5000	Up to 25 min	1.0 hour	Decay by 15%	0.75	70%	5000 kW of DR used
			2.0 hours	Decay by 15%	1.0	70%	10000 kW of DR used
Integrated Volt/var Optimization (IVVO)	3000	Up to 5 min	2 hours	±10%	0.50	90%	-

within emergency voltage limits							
Integrated Volt/var/Watt Optimization (IVVWO) within emergency voltage limits – includes demand response in voltage-critical point to increase the effectiveness of the IVVO.	6000	Up to 20 min	2 hours	Decay by 20%	1.00	80%	1000 kW of DR used
Block m+1 of Demand response							
…							
Block n+m of Demand response							

Table 9 The information presented in Table 6 shall be aggregated by the respective Data Management Systems and DMS applications, like Load Forecast, DOMA, IVVWO and serve as input data for the TBLM developer. The TBLM developer shall derive aggregated DR information in a form suitable for the EMS applications. This aggregated at the transmission bus information shall include the effect of the particular demand response alternative on the overall distribution system operations. Therefore, the DMS applications will be also used by the TBLM developer.

An example of a form that can be suitable for the EMS applications is presented in Table 10.

Table 10. Available DR prepared for EMS applications, kW/kvar

Duration of DR needed		Cost, $/kW							Total DR kW/kvar; Range of time delays
		0.04	0.55	0.6	0.70	0.8	0.9	1.0	
2 hours	kW/kvar	500/250±10%	1500/500 -15%		3000/1000-15%	3000/1000-15%	3000/1000 – 15%	8000/4000-15%	**18,500/7500 – 15%**
	Max time delay, min	2	15		20	20	20	45	**From 2 to 45 min**
	Probability of execution, %	90	85		80	80	80	80	
4 hours	kW/kvar	500/250±10%		1500/500 -15%		3000/1000 -15%	3000/1500 -15%	4000/2000 -15%	**11,500/5250 -15%**
	Max time delay, min	2		15		20	20	45	**From 2 to 45 min**
	Probability of execution, %	90		85		80	80	80	
6 hours	kW/kvar	500/250±10%			1500/750 -15%		3000/1500 -15%		**4,500/2500 -15%**

	Max time delay, min	2			15		20		**From 2 to 20 min**
	Probability of execution, %	90			85		80		

The information presented in Table 10 can be used by the EMS applications, like Contingency Analysis, Security Constrained Dispatch, Unit Commitment, Economic dispatch, Optimal Power Flow, and also for ancillary services, if supported, e.g., by the Virtual Power Plants represented by the Aggregators. If a price signal is used as a trigger for DR, the cost component presented in the aggregated model can be used as a reference for determining the effective price signal.

Table 11. Reduction of load connected to other load management alternatives after implementation of the DR (e.g., UFLS) *

Duration of DR needed		Cost, $/kW							Total kW/kvar reduction of UFLS
		0.04	0.55	0.6	0.70	0.8	0.9	1.0	
2 hours	Group 1 of UFLS	100/50	400/200		500/250	500/200	700/300	2000/1000	**4200/2000**
	Group 2 of UFLS	100/50	200/100		500/250	500/250	500/250	2000/1000	**3800/1900**
	Group 3	100/50	100/50		500/250	500/250	500/250	2000/1000	**3700/1850**

	of UFLS								
4 hours	Group 1 of UFLS	100/50		300/100		400/200	600/300	1000/500	**2400/1150**
	Group 2 of UFLS	100/50		200/100		400/200	600/300	1000/500	**2300/1150**
	Group 3 of UFLS	100/50		200/100		400/200	600/300	1000/500	**2300/1150**
6 hours	Group 1 of UFLS	300/50			250/100		600/300		**1150/450**
	Group 2 of UFLS	100/50			250/100		600/300		**950/450**
	Group 3 of UFLS	100/50			250/100		600/300		**950/450**

- This issue is presented in more details in Scenario 9

Pre-conditions. Communications with large customer and aggregators are operational. DR contracts are timely updated. Short-term load and weather forecasting applications are operational. AMI, Load, and DER Data management systems are able to adapt load models with integration of Demand Response, and derive models for non-monitored in near real-time loads with demand response and embedded DERs. The load modeling processors generate adaptive load models with and without implemented DR.

Table 12. Step-by-step actions for Scenarios 5&6.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
#	Triggering event. Identify the name of the event.[4]	What other actors are primarily responsible for the Process/Activity? Actors are defined in section[2.]	Label that would appear in a process diagram. Use action verbs when naming activity.	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.	What other actors are primarily responsible for Producing the information? Actors are defined in section2.	What other actors are primarily responsible for Receiving the information? Actors are defined in section2. (Note – May leave blank if same as Primary Actor)	Name of the information object. Information objects are defined in section 3	Elaborate architectural issues using attached spreadsheet. Use this column to elaborate details that aren't captured in the spreadsheet.	Reference the applicable IECSA Environment containing this data exchange. Only one environment per step.
1.1	Periodic or by event trigger of DOMA	DMS Scheduler	Trigger of DOMA	Start periodic or by event run of DOMA based on the last snapshot of input data	DMS Scheduler	DOMA application	DOMA start		

[4] Note – A triggering event is not necessary if the completion of the prior step – leads to the transition of the following step.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
2.1	DOMA started	DOMA	DOMA collects data on implemented DR from the Load Modeling Processor	DOMA updates adaptable load models, if needed	Load Modeling Processor	DOMA applications	Updates of adaptable load models based on data obtained from the DMS Scheduler (SCADA measurements, weather data, prices, etc.)		
2.2	DOMA started	DOMA	DOMA collects data from the DER Data Management System	DOMA updates the adaptable DER models	DER Data Management System	DOMA applications	Updates of adaptable DER models		
2.3	DOMA started	DOMA	DOMA collects data from the Load Management System	DOMA updates the states of Demand Response	Load Management System	DOMA applications	Updates of the states of Demand Response	If the Demand Response is enabled, the load composition of the participating customers is changed, and the individual load-to-voltage dependencies may be different.	

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
3	All input data is collected by DOMA	DOMA	DOMA adapts the load, DER/micro-grid, volt/var controlling devices and RAS models based on the collected data	DOMA updates the topology model based on status data, the load and DER models based on time of day, weather, and pricing data and balances the load models with DSCADA measurements by running the state estimation. DOMA updates the settings of controlling devices and RAS, and the facilities connected to the RAS	DOMA	DOMA	Adaptation of models and balancing the Load and DER injections		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
4	Periodic or by event trigger of TBLM developer	DMS scheduler	Trigger of TBLM developer	DMS scheduler initiates the periodic or by event run of the TBLM developer	DMS scheduler	TBLM developer	Initiation of the TBLM developer	The periodicity of the runs of the TBLM developer may be different from the periodicity of other DMS applications. The events for triggering the new run of the TBLM developer may include the following: Change of distribution system connectivity; change in DR contracts; sudden change in weather conditions, etc.	

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
5	TBLM developer initiates a series of look-ahead DOMA and IVVWO runs	TBLM developer	Initiation of look-ahead DOMA and IVVWO runs for the purpose of aggregated demand response modeling	The TBLM developer initiates the series of DOMA and IVVWO runs, defining a matrix of demand response amounts and durations	TBLM developer; Distribution operators	DOMA and IVVWO	Initiation and conditions of look-ahead runs of DOMA and IVVWO		
6.1	Look-ahead runs of DOMA with successive runs of IVVWO performed	IVVWO	Development of aggregated at the transmission buses DR model, like Table 6	DOMA prepares look-ahead reference models that are used by IVVWO to optimize the demand response required by the given matrix of conditions	IVVWO	TBLM developer	Matrix of available demand response conditions for given look-ahead time intervals		
7	IVVWO finished optimization of DR and modeling the aggregated DR and submitted it to the TBLM developer	TBLM developer	Preparation of the aggregated DR models for the use by the EMS applications	The TBLM developer prepares the aggregated model of the DR kWs and kvars grouped by the available duration and costs (price) for the use by the EMS applications	TBLM developer	TBLM	DR groups as available variables for EMS applications.		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
6.2	Look-ahead runs of DOMA with successive runs of IVVWO performed	IVVWO	Updating the load models after DR	IVVWO submits expected nodal load data after implementation of DR to the Load Management System	IVVWO	Load Management System (includes the RAS loads)	Updated load data after DR implementation	A portion of the load reduced by DR may be included in other load management alternatives. Some EMS applications include these alternatives as controllable variables (e.g., contingency analyses). After DR is implemented, the load connected to these schemes is reduced, which must be accounted by the corresponding EMS applications.	

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
8	Load Management System updated other load management alternatives that overlap with DR	Load Management System	Updates of overlapping with DR load management alternatives	The Load Management System determines the portions of load reduced by DR that overlaps with other load management means and distributes the updated among the corresponding groups of the load management schemes. This information is submitted to the TBLM developer for each group of DR by the groups of the load management schemes.	Load Management System	TBLM developer	Updates of other than DR load management means		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
9	The aggregated loads of other load management means after implementation of DR groups are determined by the TBLM developer	TBLM developer	Update of the models of other load management means in the TBLM	The TBLM developer prepares the aggregated models of loads connected to other than DR load management means grouped by the available duration and costs (price) and by the groups of other load management means (based information like in Table 8)	TBLM developer	TBLM	Updates of other load management means after implementation of DR		

Scenarios 7 and 8. Develop aggregated real and reactive load dependencies on ambient conditions and time.

Scope. Scenario 7 is mostly about adapting aggregated real and reactive load to current weather conditions, while scenario 8 is about developing aggregated real and reactive load dependencies on ambient conditions and time for the short-term forecast of the aggregated load. The dependencies of the aggregated load on ambient conditions include the combination of natural load dependencies, distributed generation and storage dependencies, the demand response dependencies, and the associated impacts of the distribution power flow and DMS applications. The ambient conditions include the localized temperature, humidity, wind direction and velocity, cloudiness, and sunlight.

Objectives. Adapt the TBLM attributes to the current ambient conditions and provide aggregated real and reactive TBLM dependencies on ambient conditions and time.

Background Information

The aggregated at the transmission bus load model consists of the following components:

- Natural load of different load categories, like residential, commercial, and industrial. These loads are changing in the times of day, week, season, and are also dependent on the ambient weather conditions.
- Distributed generation (DG) of different types. The reciprocating and fuel cell DG can be time dependent based on schedules, or technological cycles. The renewable DG is strongly dependent on the ambient weather, including the sunlight cycles and the intermittency of the weather. The representation of the DG injections of real power under intermittent weather conditions implies probabilistic models. In addition to statistic values of the aggregated load, such models introduce the degree of uncertainty of the model that can be used in the risk management. The injections/absorption of the DG reactive load is dependent on the performance of the real load and on the modes of volt/var control.
- Electric storage (ES). The charging/discharging times of the ES may be predominantly dependent either on the energy price or on other power system operation factors, such as ancillary services. These dependencies may be complicated by an ES optimization procedure. For instance, if it is expected that the energy price exceeds a threshold set by the ES owner two times during the day: at the morning peak and at the evening peak time, and the evening peak time price is higher, the owner of the ES will skip the morning time and will discharge the ES at the evening peak time. Also, the times and the duration of the charging/discharging of ES are dependent on the previous performance of the ES. For instance, if the ES was not discharged the previous day, it will not charge the following night. However, it is possible that for some ES installations the charging/discharging times can be set by time-schedules. Some ES can be set to compensate the fluctuations of the injections by other DGs.
- Load management capabilities, including Demand response (DR) and Remedial Action schemes (RAS). The demand response capabilities are different at different times and under different weather conditions. Here again, the relationships between the DR capabilities and the weather conditions may be not straightforward ones. For instance, under hot weather conditions, there is a greater air-conditioning load and a greater potential for DR. However, if the hot weather continues for a longer period of time, the DR potential may reduce. The RAS capabilities are also different under different weather conditions due to the changes of the amount and composition of natural load, DG and ES.
- Impacts of the central and local Volt/var/Watt control caused by the changes of the above-mentioned components. These impacts include changes of the natural real and reactive load due to the load-to-voltage dependencies, changes of the DG and

ES due to the central and/or local volt/var controls, and changes of the real and reactive power losses caused by the changes of loads, DG, ES and performance of the IVVWO.

Pre-conditions. External information sources of local weather conditions are available and are interfaced with the DMS for near real-time information support. The contents of the weather information support include the current and the short-term look-ahead ambient temperature, humidity, relevant parameters of cloudiness, wind direction and velocity, and effective sunlight. Strategically placed bellwether smart meters or other IEDs are available for near-real time reporting of the performance of the intermittent distributed generation, some of them with environmental sensors. Communications with large customer and aggregators are available. DR contracts are timely updated. Short-term load forecasting applications are operational. AMI and DER Data Management systems and Load Management systems, as well as corresponding model processors are able to provide DOMA application with updated ambient parameters and adaptive load, DG/ES, and DR models.

Table 13. Step-by-step actions for Scenarios 7 & 8.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
#	Triggering event. Identify the name of the event.[5]	What other actors are primarily responsible for the Process/Activity? Actors are defined in section[2.]	Label that would appear in a process diagram. Use action verbs when naming activity.	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.	What other actors are primarily responsible for Producing the information? Actors are defined in section2.	What other actors are primarily responsible for Receiving the information? Actors are defined in section2. (Note – May leave blank if same as Primary Actor)	Name of the information object. Information objects are defined in section 3	Elaborate architectural issues using attached spreadsheet. Use this column to elaborate details that aren't captured in the spreadsheet.	Reference the applicable IECSA Environment containing this data exchange. Only one environment per step.
1	TBLM Developer is initiated	TBLM Developer	TBLM Developer started	The TBLM Developer prepares conditions according to the needs of scenarios 7 and 8 for the development of the corresponding components of the TBLM	TBLM Developer	DOMA	Conditions for DOMA and IVVWO runs		

[5] Note – A triggering event is not necessary if the completion of the prior step – leads to the transition of the following step.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
2	TBLM developer initiates a series of DOMA and IVVWO runs in study modes	TBLM developer	Initiation of study DOMA and IVVWO runs for the purpose of adapting the TBLM attributes to the current ambient conditions	The TBLM developer initiates the series of DOMA and IVVWO runs, defining the attributes of TBLM to be adapted to the current ambient conditions, such as: • load models, including the probabilistic characteristics • capability curves • load-to- voltage and frequency dependencies • demand response	TBLM developer	DOMA and IVVWO	Initiation of series of near-real-time runs of DOMA and IVVWO		
3	The series of DOMA and IVVWO complete	TBLM developer	TBLM developer processes the results of DOMA and IVVWO series	TBLM developer summarizes the results of the DOMA and IVVWO series into aggregated TBLM attributes	TBLM developer	TBLM	Aggregated TBLM attributes		

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
4	TBLM developer triggers the Look-ahead runs of DOMA with successive runs of IVVWO	TBLM developer	Triggering the look-ahead series of DOMA and IVVWO for TBLM forecast	TBLM developer defines the ambient conditions based on the available forecasts and triggers the runs of DOMA under these conditions and for look-ahead timeframes. These DOMA reference models are used by IVVWO to finalize the aggregated effect of the ambient conditions at the given times	TBLM developer	DOMA	Array of predefined ambient conditions for given look-ahead time intervals		
5	DOMA and IVVWO finished the series of optimization of the look-ahead operating conditions	TBLM developer	TBLM developer processes the results of the look-ahead DOMA and IVVWO series	TBLM developer summarizes the results of the look-ahead DOMA and IVVWO series into the look-ahead aggregated TBLM attributes	TBLM developer	TBLM	Look-ahead aggregated TBLM attributes		

Scenario 9. Develop models of overlaps of different load management functions, which use the same load under different conditions

Scope. The load management can be executed through several programs, such as:

- Volt/var control in distribution

- Dynamic pricing
- Demand response/direct load control
- Interruptible load/Load curtailment
- Remedial Actions
    - Under-frequency load shedding
    - Under-voltage load shedding
    - Predictive/special load shedding

All of these load management means result in changes of both real and reactive load. The impact of these means on load is different. The Volt/var control and the dynamic pricing are, probably, the least influential on the real load due to the limited load elasticity to them. However, the Volt/var control can significantly impact the reactive load.

The Demand response/direct load control and the Interruptible load/load curtailment may be in the range of single-digit percentage on the average, but can be greater in local areas. The same load can be included in these two programs. The effect of the overlapping of these loads should be taken into account, when considering load reduction in the timeframes of these programs.

The most significant load reduction results from the remedial actions, and the greatest overlaps of the load under these programs can be expected. If the remedial actions are executed, the loads under the slower load management means are also reduced, because, most likely, the load included in these slower means are also included in the remedial action schemes.

Objectives. Provide the TBLM with near-real time updates of the effective load management means operating in sequences, taking into account the load overlaps between different means. These models will be used by the EMS applications, especially by the contingency and security analyses used for the self-healing operations of electric power systems.

Background Information

Some of the least-intrusive load management means can be expected to be used as variables under normal operating conditions. For instance, optimization EMS functions with the objectives of energy cost reduction may use load-reducing volt/var control in distribution and/or demand response.

A more critical use of load management means is a part of the steady-state and dynamic analyses of emergency situations. With high penetration of DER in distribution and with the real threat of compromising the cyber security, an exponential growth of the variety of possible emergency situations can be expected. This requires N-m (instead of N-1) analyses and also increases the probability of cascading development of emergencies.

An example of such combinations is presented in Table 14.

Table 14. Example of possible N-m combinations of emergencies*.

	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**
a. Loss of transmission lines	-			X			X	X	X	X
b. Loss of generating units		-			X		X	X	X	X
c. Loss of bus section	X		-	X			X	X	X	X
d. Loss of transformers (auto-transformers)				-			X	X	X	X
e. Loss (or lack of dynamic reserve) of reactive power source, e.g., SVC					-			X	X	X
f. Loss of substation (one voltage level plus transformers)	X		X	X	X	-	X	X	X	X
g. Failure of Remedial Action System							-			
h. Loss of significant DER in distribution								-		
i. Failure of software (cyber-security)	X	X	X	X	X	X	X		-	X
j. Loss of critical communications	X	X	X	X	X	X	X			-

*On the top of this complicating factors are possible, e.g., delayed clearance of a fault, erroneous operations of personnel, etc.

With such a diversity of combinations of contingencies different sequences of load reducing/shedding actions are possible. Therefore, the overlapping of loads among different load management schemes may impact the development of the contingencies.

Consider an example for two Remedial Action Schemes (RAS): Under-Frequency Load Shedding (UFLS) and Under-Voltage Load Shedding (UVLS). Some portions of the load connected to the UFLS and UVLS schemes may be the same. It means that if the voltage drops below a UVLS setting before the frequency drops below the UFLS settings, a portion of the shed load, which is also a part of the UFLS, is excluded from the UFLS scheme, and, when the frequency drops below the UFLS settings, the load shed by the UFLS will be smaller, and vice versa. This overlapping of the loads connected to the Remedial Action Schemes shall be presented and timely updated in the TBLM. Table 15 illustrates a possible template for the representation of the overlapping loads. For instance, the total load connected to group 1 of the UVLS scheme is kW-V1. The total load connected to group 1 of the UFLS scheme is kW-F1. The common load that belongs to group 1 of UVLS and to group 1 of the UFLS is kW-FV11. If the voltage drops below the settings of UVLS group 1 before the frequency drops below the setting of UFLS group 1, then the actual load connected the UFLS group 1 will became (kW-F1) – (kW-FV11). If the frequency drops below the settings of UFLS group 1 before the voltage drops below the settings of UVLS group 1, then the actual load connected to the UVLS group 1 will become (kW-V1) – (kW-FV11).

Table 15. Overlapping load in UFLS and UVLS groups

		UVLS groups		
		1	2	3
UFLS Groups	Connected load	kW-V1	kW-V2	kW-V3
1	kW-F1	kW-FV11	kW-FV12	kW-FV13
2	kW-F2	kW-FV21	kW-FV22	kW-FV23
3	kW-F3	kW-FV31	kW-FV32	kW-FV33

It becomes more complicated if there are more than two load management programs with load overlap. Consider an example. There is a predictive load shedding scheme, which quickly operates when the transfer capability of a transmission corridor is critically reduced.

However, when this load shedding is executed, the voltage at the receiving end may drop below some under-voltage load shedding settings (the predictive load shedding is determined based on predictions with some degree of uncertainty and may be insufficient during the time of abnormal operating conditions). So, when the voltage drops below the settings of UVLS, the UVLS sheds the load connected to the corresponding group less the load shed by the predictive load shedding. A portion or the entire load that remained under the UVLS scheme can be also connected to the UFLS schemes. So, the capability of UFLS will be reduced after UVLS operates. In a cascading contingency, the voltage deficiency may lead to further loss of generation support and to a frequency deficiency. In this case, the UFLS will be enabled.

Such kind of sequence of event may be considered in transmission contingency analyses. Therefore a set of models updated in the near-real time manner would provide the contingency analysis applications with the necessary information.

The TBLM shall also support information about the relationships between different load-management and load-shedding means for the same bus, i.e. how each available load reduction/shedding depends on the previously executed load reduction by other means. Examples of such relationships are presented in the tables below:

Table 16. Common load for a portion (group) of load management means

Load Reduction Means	% of total load connected to the load management means	Percentage of total load included in both load management means						
		Demand response	Load curtailment	Voltage reduction	Block Load Shedding	Predictive LS	UFLS	UVLS
Demand response	5	5	0	0.15	0.384	0.72	0.624	0.48
Load curtailment	4	0	4	0.12	0.32	0.6	0.52	0.4
Voltage reduction	3	0.15	0.12	3	0.24	0.45	0.39	0.3
Block Load Shedding	8	0.384	0.32	0.24	8	1.2	1.04	0.8
Predictive LS	15	0.72	0.6	0.45	1.2	15	4.3	3.3
UFLS	13	0.624	0.52	0.39	1.04	4.3	13	5
UVLS	10	0.48	0.4	0.3	0.8	3.3	5	10

Table 17. Effective load management capabilities after one load management means is executed

Load Reduction Means	% of total load connected to the load management means	Percentage of total load after the following load reduction is implemented						
		Demand response	Load curtailment	Voltage reduction	Block Load Shedding	Predictive LS	UFLS	UVLS
Demand response	5		5	4.85	4.616	4.28	4.376	4.52
Load curtailment	4	4		3.88	3.68	3.4	3.48	3.6
Voltage reduction*	3	2.85	2.88		2.76	2.55	2.61	2.7
Block Load Shedding	8	7.616	7.68	7.76		6.8	6.96	7.2
Predictive LS	15	14.28	14.4	14.55	13.8		10.67	11.67
UFLS	13	12.376	12.48	12.61	11.96	8.67		8
UVLS	10	9.52	9.6	9.7	9.2	6.67	5	

- The load reduction due to the voltage reduction may increase after other load management means are executed because of reduction of the voltage drops and increase in the tolerances for voltage reduction. This effect is not included in these numerical examples.

Table 18. Common load for a portion (group) of load management means after the predictive load shedding option is executed

Load Reduction Means	% of total load connected to the load management means	Percentage of total load included in both load management means						
		Demand response	Load curtailment	Voltage reduction	Block Load Shedding	Predictive LS (implemented)	UFLS	UVLS
Demand response	4.28	4.3	0.0	0.1	0.3		0.4	0.3
Load curtailment	3.4	0.0	3.4	0.1	0.2		0.3	0.2
Voltage reduction	2.55	0.1	0.1	2.6	0.2		0.2	0.2
Block Load Shedding	6.8	0.3	0.2	0.2	6.8		0.6	0.5
Predictive LS								

UFLS	8.67	0.4	0.3	0.2	0.6		8.7	3.3
UVLS	6.67	0.3	0.2	0.2	0.5		3.3	6.7

Table 19. Effective load management capabilities after the predictive load shedding option is implemented and another load management means is executed

Load Reduction Means	% of total load connected to the load management means	Percentage of total load after the following load reduction is implemented						
		Demand response	Load curtailment	Voltage reduction	Block Load Shedding	Predictive LS (implemented)	UFLS	UVLS
Demand response	4.28		4.28	4.17	3.95		3.86	3.96
Load curtailment	3.4	3.4		3.31	3.17		3.11	3.17
Voltage reduction	2.55	2.44	2.46		2.38		2.33	2.38
Block Load Shedding	6.8	6.47	6.57	6.63			6.21	6.35
Predictive LS								
UFLS	8.67	8.25	8.37	8.45	8.08			5.33
UVLS	6.67	6.34	6.44	6.50	6.21		3.33	

Table 20. Common load for a portion (group) of load management means after the predictive load shedding and UVLS options are executed

Load Reduction Means	% of total load connected to the load management means	Percentage of total load included in both load management means						
		Demand response	Load curtailment	Voltage reduction	Block Load Shedding	Predictive LS (implemented)	UFLS	UVLS (Impl.)
Demand response*	3.96	3.96	0.00	0.09	0.31		0.26	
Load curtailment *	3.17	0.00	3.17	0.08	0.20		0.17	
Voltage reduction**	2.38	0.09	0.08	2.38	0.15		0.13	
Block Load Shedding	6.35	0.31	0.20	0.15	6.35		0.34	

Predictive LS								
UFLS	5.33	0.26	0.17	0.13	0.34		5.33	
UVLS								

Table 21. . Effective load management capabilities after the predictive load shedding and UVLS options are implemented and another load management means is executed

Load Reduction Means	% of total load connected to the load management means	Percentage of total load after the following load reduction is implemented						
		Demand response	Load curtailment	Voltage reduction	Block Load Shedding	Predictive LS (implemented)	UFLS	UVLS (Impl.)
Demand response	3.96		3.96	3.86	3.65		3.70	
Load curtailment	3.17	3.17		3.10	2.97		3.00	
Voltage reduction	2.38	2.29	2.30		2.23		2.25	
Block Load Shedding	6.35	6.04	6.15	6.20			6.01	
Predictive LS								
UFLS	5.33	5.08	5.16	5.21	4.99			
UVLS								

An example of a decline in the capabilities of the load management means due to a sequence of execution is presented in Figure 38.

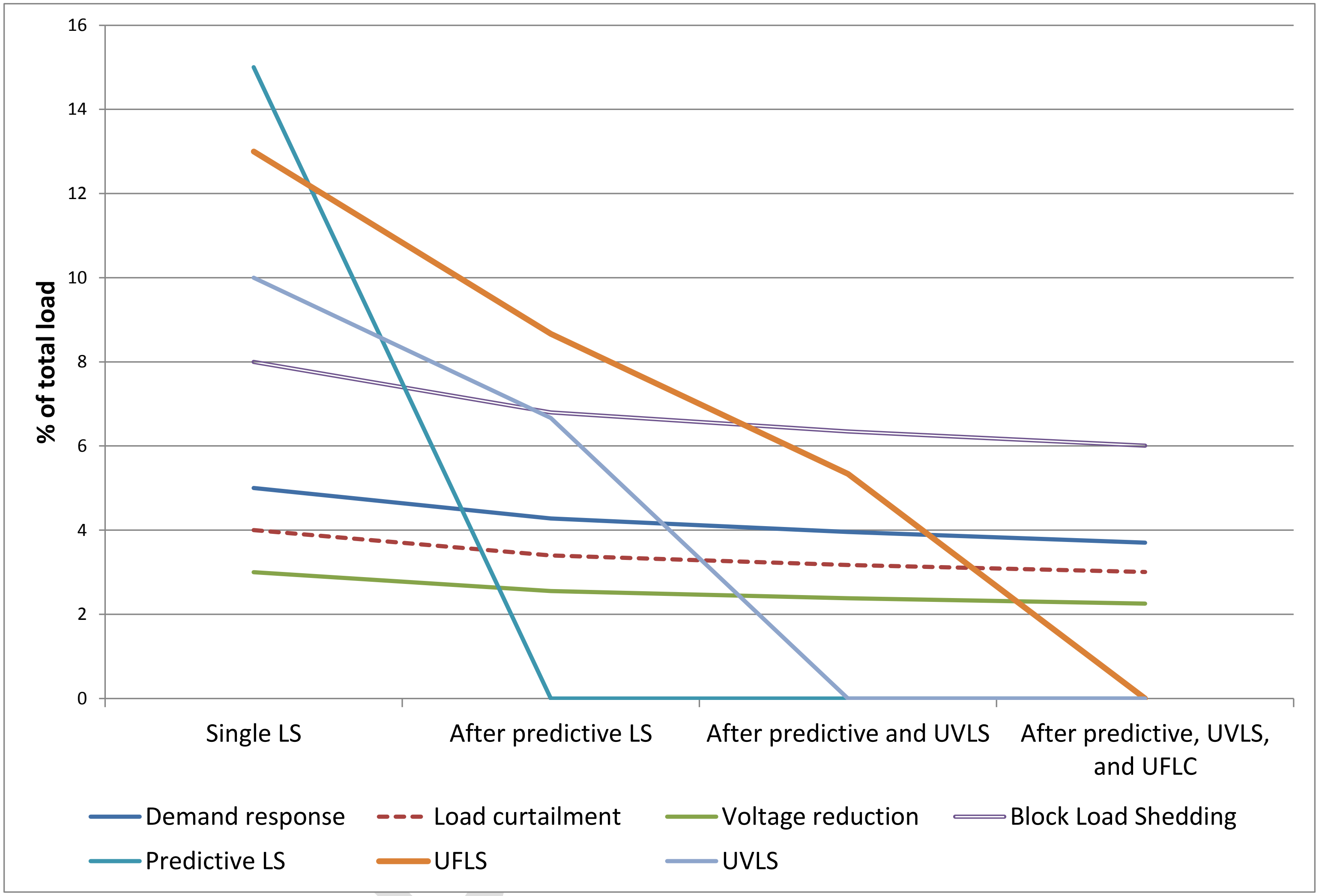


Figure 38. Effective load shedding capabilities of different load management means in a sequence of execution

The composition of nodal loads connected to different RAS may change in time due to the adaptive nature of preventive and corrective measures for the self-healing operations and due to the changing availability of other load management means, e.g., due to the contractual conditions of the demand response programs. This changing information should be updated via near-real time information exchange between the corresponding primary sources of information and the Data Management Systems.

Pre-conditions. The Load Management System (LMS) contains the updated information on the different "normal" load management means by groups on a nodal ID bases. This information is updated by the corresponding Data Management Systems. The LMS also contains the information on the elements of RAS by groups. This information is defined by the IDs of the switching devices affected by the corresponding groups of the RAS. Communications with large customer and aggregators are available. DR contracts are timely updated. Short-term load forecasting applications are operational.

Table 22. Step-by-step actions for Scenarios 9

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments

#	Triggering event. Identify the name of the event.[6]	What other actors are primarily responsible for the Process/Activity. Actors are defined in section[2.]	Label that would appear in a process diagram. Use action verbs when naming activity.	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.	What other actors are primarily responsible for Producing the information? Actors are defined in section2.	What other actors are primarily responsible for Receiving the information? Actors are defined in section2. (Note – May leave blank if same as Primary Actor)	Name of the information object. Information objects are defined in section 3	Elaborate architectural issues using attached spreadsheet. Use this column to elaborate details that aren't captured in the spreadsheet.	Reference the applicable IECSA Environment containing this data exchange. Only one environment per step.
1.1	Change of Load Management Parameters monitored by SCADA/EMS or SCADA	SCADA/EMS or DSCADA IDs	Update of SCADA/EMS or DSCADA on load management information	The changes may include: change of switch ID participating in RAS; change of settings of RAS, etc.	SCADA/EMS or DSCADA IDs	SCADA databases	Updated load management information	The information includes data models of RAS	IEC 61850
1.2	Change of Load Management Parameters monitored by other Data Management Systems	AMI, CEMS, DER controllers, Micro-grid controllers	Update of Data Management Systems on load management information	The changes may include: change of demand response parameters; change of switch ID participating in RAS; change of settings of RAS, etc.	AMI, CEMS, DER controllers, Micro-grid controllers	Data Management Systems	Updated load management information	The information includes data models of DR, interruptible/curtainable loads, RAS	IEC 61850, ANSI C12x, ….

[6] Note – A triggering event is not necessary if the completion of the prior step – leads to the transition of the following step.

2.1	Load Management System obtained updated information on load management	Load Management System	Update of Load Management System on load management data	The load management system obtains new data on the Demand response participation; RAS allocation and settings.	DMS Scheduler; AMI Data Management System; DER Data Management System/DER Model Processor	Load Management System	Updated data on load management		
3.1	Periodic or by event trigger of DOMA	DMS Scheduler	Trigger of DOMA	Start periodic or by event run of DOMA based on the last snapshot of input data	DMS Scheduler	DOMA application	DOMA start	The triggering events in this case are the ones that are obtained by the DMS scheduler from DSCADA or EMS SCADA.	

3.2	By event trigger of DOMA from Load Management Systems or Model Processors	Load Manageme nt Systems/M odel processors	Trigger of DOMA	Start by-event execution of DOMA based on a change in conditions of either normal, or emergency load management means	Load Management Systems	DOMA application	DOMA start	The change may include: significant change in Demand Response participation; re-allocation of interruptible /curtailable loads; re-allocation or change of settings of UFLS and/or UVLS, etc.	
4.1	DOMA started	DOMA	DOMA collects relevant data from the last consolidated snapshot provided by the DMS scheduler	DOMA updates the topology model and other status and analog data	DMS Scheduler	DOMA applications	Updates of the models based on data obtained from the DMS Scheduler	DOMA collects data from the snapshot on circuit topology, SCADA measurements, and load management means by corresponding IDs of switching devices.	

4.2	DOMA started	DOMA	DOMA collects relevant data from the Load Management System/ Load Model Processor	DOMA updates adaptable load models, including the parameters of load management.	Load Management System	DOMA applications	Updates of adaptable load models based on data obtained from the Load Management System/ Load Model Processor	DOMA collects data from the Load Management System on allocation of DR by node IDs, and on other load management means by corresponding IDs of switching devices.	

5.1	All input data is collected by DOMA	DOMA	DOMA adapts the operation model.	DOMA updates the topology model based on status data, the load and DER models based on time of day, weather, and pricing data and balances the load models with DSCADA measurements by running the state estimation. DOMA updates the settings of controlling devices and RAS, and the facilities connected to the RAS.	DOMA	DOMA	Adaptation of models and balancing the Load and DER injections. Based on the results of the state estimation, on the data on load management means, and on the allocation of the load management switching devices, DOMA develops matrices of all relevant load management means and overlapping loads between them (like Table 16). Optional: DOMA develops chain scenarios of the execution of the load management alternatives.	It is suggested that this activity is performed by DOMA because DOMA possesses all needed information on load management, circuit topology, and the impact of the load management on the power flow results. The optional DOMA activity would yield a more accurate result in comparison with the TBLM developer due to the ability of DOMA to include effect of the load management on the power flow.	

5.2	All input data is collected by DOMA	DOMA	DOMA initiates the runs of study IVVWO	DOMA initiates the run of IVVWO to determine the load management capability of IVVO for the initial state and for the chain scenarios, if they are performed by DOMA	DOMA	IVVWO	Initiation of IVVWO runs	There are two effects of IVVWO on load management: The load reduction by IVVWO is smaller due to eliminating of participating loads shed by other means and the load reduction is increased due greater tolerances for voltage reduction because of the lighter loading and smaller voltage drops. That is why it is recommended running the chain scenarios by DOMA and IVVWO instead of by the TBLM developer.	

6	DOMA and IVVWO completed the series of runs	DOMA and IVVO	Trigger of TBLM developer	DOMA and IVVWO provides the TBLM developer with results of the series of executions to initiate the TBLM developer.	DOMA and IVVWO	TBLM developer	Initiation of the TBLM developer	The periodicity of the runs of the TBLM developer for the load management purposes may be different from the periodicity for other purposes. The events for triggering the new run of the TBLM developer for the updates of the load overlapping models are the completion of DOMA and IVVWO and the presence of significant changes.	

7.1	TBLM developer is initiated	TBLM developer	Update of the TBLM	The TBLM developer verifies the models and transmits the near-real time results of the DOMA and IVVWO runs to the TBLM	TBLM developer	TBLM	Update of TBLM with current models for load management	The TBLM developer submits verified results, like in Table 17 through Table 21 in the examples above. (The verification criteria are to be developed)	

7.2	TBLM developer is initiated	TBLM developer	Initiation of a set of look-ahead DOMA and IVVWO runs for the purpose of future load management models	The TBLM developer initiates the series of DOMA and IVVWO runs, defining the times for the look-ahead studies according to the setup of the look ahead requirements for the TBLM	TBLM developer	DOMA and IVVWO	Initiation and conditions of look-ahead runs of DOMA and IVVWO for the load management models	The EMS network analysis and optimization applications may be setup for particular look-ahead time frames and with particular resolutions, e.g., for three hours ahead divided into 30-minute intervals. Then, the EMS application may run for the worst-case scenario during this time. The forecasted models for the time of the worst-case scenario should be available.	

8	Look-ahead runs of DOMA and IVVWO finished	IVVWO	Development of the look-ahead models of load management.	DOMA and IVVWO submits the look-ahead load management models to the TBLM developer	DOMA and IVVWO	TBLM developer	The TBLM developer verifies the set of matrices for the look-ahead load management models and submits them to the TBLM.		

Scenario 10. Assess the degree of uncertainty of TBLM component models

TBD

Scenario 11. Develop Virtual Power Plant models

TBD

References and contacts

Documents and individuals or organizations used as background to the function described; other functions referenced by this function, or acting as "sub" functions; or other documentation that clarifies the requirements or activities described. All prior work (intellectual property of the company or individual) or proprietary (non-publicly available) work must be so noted.

FUTURE USE

ID	Title or contact	Reference or contact information
[1]		
[2]		

6 Action Item List

As the function is developed, identify issues that still need clarification, resolution, or other notice taken of them. This can act as an Action Item list.

FUTURE USE

ID	Description	Status
[1]		
[2]		

7 References

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17. http://www.sce.com/b-rs/demand-response-programs/demand-response-programs.htm

For reference and tracking purposes, indicate who worked on describing this function, and what aspect they undertook.
FUTURE USE

No	Date	Author	Description
1	12/2010	Nokhum Markushevich	Use_cases_for_the_Self-healing_Grid-nm.pdf -12/2010
2	3/11	Nokhum Markushevich	Contribution to Pap 14: The Need to Develop the Transmission Bus Load Model as a Key Application Framing Use Case for Priority Action Plan 14 "T&D Systems Models
3	3/11	Joe Hughes	Additions to the " The Need to Develop the Transmission Bus Load Model as a Key Application Framing Use Case for Priority Action Plan 14 "T&D Systems Models"
4	3/11	Nokhum Markushevich	Presentation_to_SGIP:_Transmission Bus Load Model – the Bridge for Cross-Cutting Information Exchange between Distribution and Transmission Domains

No	Date	Author	Description
5	4/11	Nokhum Markushevich	Smart Grid Focused Use Cases for Transmission and Distribution Operations
6	4/11	Nokhum Markushevich	Some considerations of operations of PV inverters in Electric Power Systems (for inclusion in the TBLM)
7	5/11	Nokhum Markushevich	Tentative_List_of_Transmission_Operation_Functions_for_Development_of_Use_Cases_for_PAP_14
8	10/11	Nokhum Markushevich	TBLM narrative- presented at DEWG: Information Exchange Between Transmission and Distribution Domains
9	10/11	TnD DEWG	Discussion on “Information Exchange Between Transmission and Distribution Domains”
10	10/11	Nokhum Markushevich	Presented at DEWG: Major actors of the high level TBLM use case
11	10/11	TnD DEWG	Discussion on “Major actors of the high level TBLM use case”
12	10/11	Nokhum Markushevich	Presented at DEWG: Preconditions for TBLM Use Case
13	10/11	Joe Hughes	Additions to Preconditions for TBLM Use Case
14		TnD DEWG	Discussion on “Preconditions for TBLM Use Case”
15	11/11	Nokhum Markushevich	Presented at DEWG : TBLM - Cross-cutting aspects
16	11/11	TnD DEWG	Discussion on “TBLM - Cross-cutting aspects”
17	11/11	Nokhum Markushevich	Presented at DEWG: TBLM Interfaces

No	Date	Author	Description
18	11/11	Nokhum Markushevich	Update of the TBLM activity diagram
19	11/11	Nokhum Markushevich	Updates on Major actors and on Interfaces
20	12/11	Nokhum Markushevich	Presented at DEWG: Draft list of Scenarios for TBLM Use Cases
21	12/11	TnD DEWG	Discussion on "Draft list of Scenarios for TBLM Use Cases"
22	12/11	Nokhum Markushevich	Presented at DEWG: TBLM Use Case Narrative - Scenarios 1&2
23	12/11	TnD DEWG	Discussion on "TBLM Use Case Narrative - Scenarios 1&2"
24	12/11	Nokhum Markushevich	Draft function description, narrative, actors, Interfaces, preconditions, activity diagram in the SGIP template
25	12/28	Nokhum Markushevich	Updated the Activity Diagram and the description of the interfaces. Expanded the narrative for the TBLM. Added the narrative and steps for scenario 1 and 2.
26	01/16/12	Nokhum Markushevich	Added scenario 3
27	01/24/12	Nokhum Markushevich	Added scenario 4
28	01/25/12	TnD DEWG	Discussion on Version 3
29	02/15/12	Nokhum Markushevich	Added Scenario 5 and 6 (incomplete)
30	02/27/12	Nokhum	Added to narrative and step table for Scenario 5 & 6

No	Date	Author	Description
		Markushevich	
31	03/05/12	Nokhum Markushevich	Added scope, objectives, narrative, and pre-conditions for scenarios 7 &8. Started the step table. Revision of the general interfaces and the diagram.
32	03/07/12	Nokhum Markushevich	Developed step table for common information exchange between the primary sources of information, including field IEDs, and the Data Management Systems; updated the scope, objectives, narrative for scenarios 7 &8; finished the step table for scenarios 7 & 8
33	03/12/12	Nokhum Markushevich	Developed the narrative for scenario 9, numerical examples
34	03/14/12	Nokhum Markushevich	Completed draft step-by-step table for scenario 9

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[1] Triggering Event corresponds to a ClassifierRole that serves as an Activator.

[2] Information receiver corresponds to a ClassifierRole having a base Classifier assigned to an existing Actor, Classifier or Interface.

[3] Name of Activity corresponds to name attribute of an Action.

[4] Description of Activity corresponds to documentation attribute of an Action.

[5] Information receiver corresponds to a ClassifierRole having a base Classifier assigned to an existing Actor, Classifier or Interface.

[6] Information producer corresponds to a ClassifierRole having a base Classifier assigned to an existing Actor, Classifier or Interface.

[7] Name of Info Exchanged corresponds to the name attribute of a Message.

[8] TBD – Constraint attribute of some or multiple relationships?